Application of Hyperspectral Data for Forest Stand Mapping

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ABSTRACT

The objectives of this study are to evaluate the potential of Hyperspectral Mapper (HyMap) data and a spectral mixture model to characterize forest stands in a mixed coniferous and deciduous forest.

A HyMap image was flown over a standard research site in Western Switzerland in summer 1998. The research forest-site can be characterized as heavily mixed forest. HyMap data were used to map the forest mixture-grade.

The image was first evaluated qualitatively. There were no obvious noticeable geometric and radiometric errors. The HyMap image was geocoded using a parametric method (PARGE) based on a high-resolution digital elevation model and the simulation of the flight path. The image was also atmospherically corrected using ATCOR-4. Noisy wavebands were excluded.

A linear unmixing method was used to model the spectral signature of each pixel. The image based endmember collection approach to derive the spectra for selected endmembers (pure coniferous, pure deciduous, clear cutting and shadow) was performed using high resolution airphotos.

The fraction components derived from the unmixing model were compared with CIR-airphotos at the scale of 1:9000. The results show the capacity of hyperspectral HyMap data, and that linear unmixing models are very useful tools for automatically separating coniferous and deciduous stands and their mixture-grade, which is very important for forest management.

Key words: Hyperspectral, Forest Stand Mapping, Linear Spectral Unmixing

1. Introduction

Forest planning and management require information about forest resources. One of the most important information is the spatial distribution of trees in mixed species forest canopies. Most remote sensing systems in the past decades rely on measured reflectance data in a few broad wavelength bands. Current research is focused on the mapping of forest stands and determining their quantitative parameters using reflectance spectra recorded by airborne imaging spectrometry and its analysis methods such as spectral unmixing. It should significantly improve the accuracy of classic remote sensing methods in assessing the forest resources. Davison et al (1999) evaluated the ability of airborne CASI data to determine various forest parameters for boreal forests in Northern Ontario. This investigation points to the ability of CASI data to separate the major species. Goodenough et al (1999) also investigated with AVIRIS hyperspectral imagery forest parameters estimation in rugged terrain and unmanaged forest stands. The AVIRIS data showed good promise of being able to estimate some forest stands parameters. The aim of this experiment is to evaluate the potential of HyMap spectral data and a spectral mixture model to characterize forest stands in a mixed forest.

2. Test area

The study area (Kuettigkofen, Limpach Valley) is a research test site of the Department of Geography of the University of Zurich. It is located in North-Western Switzerland and covered by forest and intensively cultivated agricultural area. The research forest-site can be characterized as heavily mixed forest.

3. Data

A dataset of the Australian HyMap sensor, acquired in summer 1998 has been used. The HyMap sensor is a 128-channel high-resolution airborne imaging spectrometer operating over the wavelength range from 450 to 2480 nm. Figure 1 shows

spectral band positions of HyMap. The flight altitude was approximately 3500 m a.s.l, resulting in a ground resolution of 7.5 m in along track and 7 m in across track. The flightline is recorded using a differential GPS on board.
In order to evaluate the accuracy of the forest stand map obtained from hyperspectral data, color infrared airphotos at a scale of 1: 9000, which were also taken in summer 1998, were used (Figure 2). A fine digital elevation model and an accurate digital topographic map were also used for the geometric correction.

Spectral configuration			
Modules	Spectral range	Bandwidth across module	Average spectral sampling interval
VIS	0.45 - 0.89 um	15 - 16 nm	15 nm
NIR	0.89 - 1.35 um	15 - 16 nm	15 nm
SWIR1	1.40 - 1.80 um	15 - 16 nm	13 nm
SWIR2	1.95 - 2.48 um	18 - 20 nm	17 nm

Figure 1: Spectral band positions of HyMap (Cocks et al, 1998)

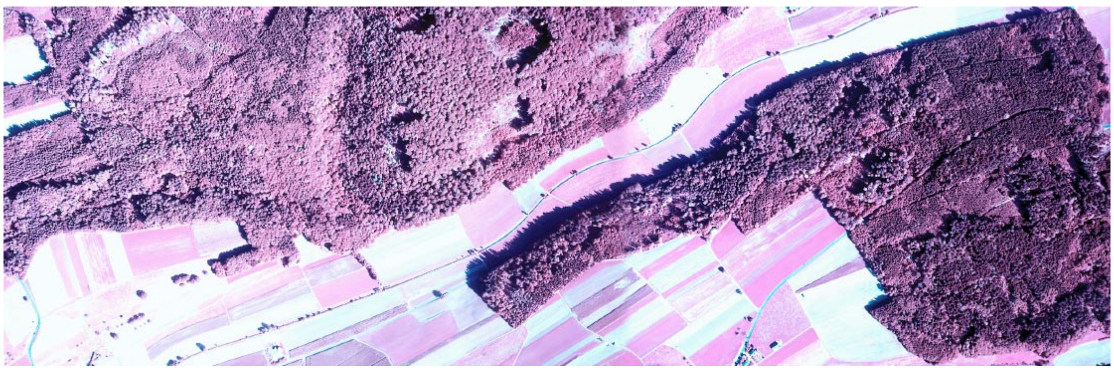

Figure 2: Color infrared airphoto of the study site, which used to evaluate the analysis.

4. Methods

4.1. Data quality analysis

Signal to noise ratio (SNR) is one of the most important indicators of data quality in hyperspectral data. The SNR has been calculated in a small homogenous field using equation 1 (Schowengerdt, 1997). The SNR were relatively high. The noisy bands 1, 2, 65, 66, 97 and 128 were set to zero reflectance and not included in further analysis.

$$SNR_i = \frac{\overline{DN_i}}{\sigma_i} \qquad (1)$$

with

SNR_i = signal to noise ratio in channel i

$\overline{DN_i}$ = Mean in channel i

σ_i = Standard Deviation in channel i

4.2. Geometric correction and registration

Since the HyMap data is obtained by an airborne system, geometric distortions occurred due to variations of the flightline as well as the attitude (roll, pitch, and yaw). These distortions could not be corrected perfectly by non parametric georeferencing methods. Therefore, the HyMap image was corrected and geocoded using a parametric approach (PARGE) including a high resolution digital elevation model (DEM) and the simulation of the flightpath of the aircraft (Schlaepfer et al 1998). The geocoded image was checked for reliability in comparison with a digital topographic map.

4.3. Atmospheric correction

The pre-processing of the HyMap data was performed by DLR. The delivered data was radiance-calibrated. In addition an atmospheric correction has been achieved applying the ATCOR-4 code (Richter, 1996). This program accounts for sensor characteristics and illumination effects. The correction process was performed using a US-standard atmosphere and a horizontal visibility of 23 km.

4.4. Linear spectral unmixing

In a traditional classification process it is assumed that each sensors ground resolution element should be covered by a single feature, and therefore each pixel should be mapped into one of the desired classes. This assumption is unrealistic. For multi- and hyperspectral data analysis a technique has been developed which can overcome some problems of traditional approaches. This approach attempts to model spectral reflectance signature as a mixture of pure-features (endmembers). This approach has been known as linear spectral mixture analysis. Spectral mixture analysis assumes that most of the spectral variations in multispectral images are caused by mixtures of a limited number of surface materials (ie, vegetation, soil, shade), and that these components have different reflectance spectra. They commonly mix at the sub-pixel scale, producing mixed-pixel spectra. As a first approximation, spectral mixing may be modeled as a linear combination of pure components (endmember) spectra (Hill, 1993):

$$R_\lambda = \sum_{i=1}^{n} f_i \times r_{i\lambda} + \varepsilon_i \qquad (1)$$

with condition:

$$\sum_{i=1}^{n} f_i = 1 \qquad (2)$$

with

R_λ = Reflectance of mixed pixel in wavelength λ
f_i = Abundance of the endmember i
$r_{i\lambda}$ = Reflectance of the component i in wavelength λ
ε_λ = Residual error in wavelength λ

The output of linear unmixing includes an abundance and a RMS image for every selected endmember.
The validity of a mixing model can be analyzed by calculating an average root-mean-squared (RMS) error between the modeled and the measured reflectance of pixels. The abundance should have a value between 0 and 1. But if the response of a pixel is purer than the selected endmembers, abundances greater than 1 and lower than 0 will occur. The endmember spectra can be collected with different approaches such as image based, spectroradiometric field measurement and spectral libraries.

5. Results

The quality analysis of HyMap imagery indicated that they have a high signal to noise ratio, and only 6 bands were noisy. Geometric correction of the HyMap image using the PARGE code based on a high-resolution digital elevation model and the simulation of the flight path resulted a reliable image in comparison with a digital topographic map. The image could be atmospherically well corrected using ATCOR-4 program. Edmember collection based on airphoto and fieldwork caused well distinguished spectra for the selected endmebers. Figures 3 displays the spectra of the desired features. The performed linear spectral unmixing based on extracted spectra resulted the reliable abundance images. The values of the calculated RMS image were very low. Only a little portion of the abundance images have values greater than 1. This approved the validation of the mixing model. A color composite image was made from abundance images. It can be assumed as a qualitative mixture-grade stand map (Figure 4). In Figure 4, the light violet areas are pure coniferous, light green are pure deciduous and mixed violet-green color represents the mixed stands (black is the non-forest area). A visual comparison between this color composite and color infrared airphoto indicates the validation of the calculated abundances and usefulness of the unmixing model.

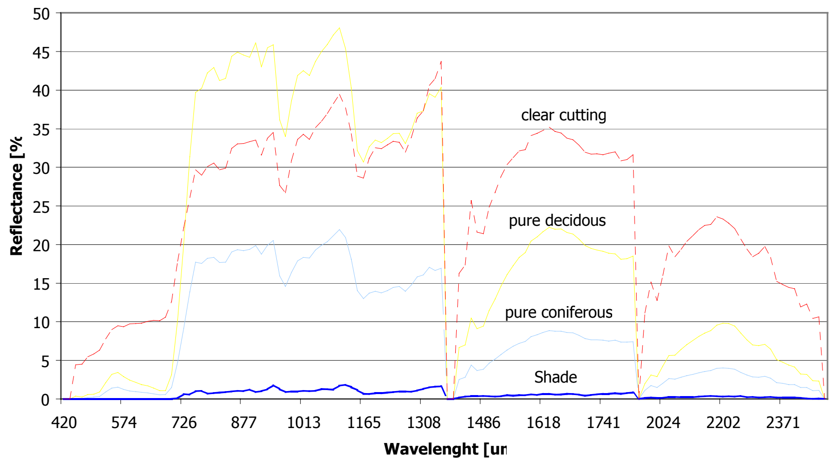

Figure 3: Reflectance spectra of four selected endmembers: pure coniferous, pure deciduous, clear cutting and shade.

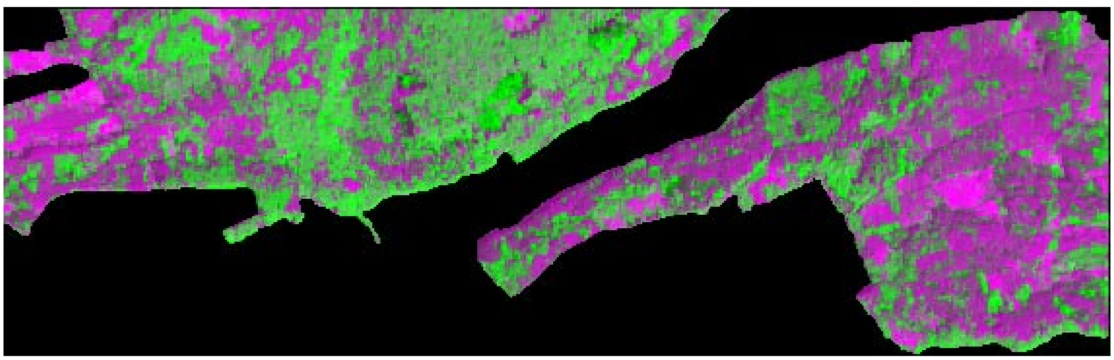

Figure 4: Quantitative mixture-grade stand map from the calculated fraction components. Pure coniferous: violet, pure deciduous: green

6. Conclusion

This investigation showed the quality of HyMap data and provided a demonstration of the application of Hyperspectral remote sensing in forestry. Comparisons between abundance components derived from HyMap data using the unmixing model, with color infrared airphotos at the scale of 1:9000 show the high potential of HyMap data, and that the linear unmixing model is a very useful tool for automatically separating coniferous and deciduous stands and their mixture-grade classes, which are very important for forest management. Using this model with hyperspectral data is a reliable method to produce a qualitative mixture-grade stand map (Figure 4). Since the reflectance of the phenomena which lie in a pixel do not mix linearly, it is not easy to derive a quantitative mixture-grade stand map from the calculated fraction components.

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