SENSITIVITY ANALYSIS OF HYMAP DATA FOR AGRICULTURAL APPLICATIONS

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ABSTRACT
The quality of results in hyperspectral image interpretation is not only depending on the algorithms employed for the parameterization of ecologically meaningful variables and processes, but also determined by the information content inherent in the regarded airborne hyperspectral measurements. For a test site in SW-Germany hyperspectral data from the Hyperspectral Mapping System (HyMap) have been used for determining the ability to detect different crops. Pre-processing included a parametric geocoding approach and the conversion of radiance data to reflectance. High geometric accuracy cadastral information was combined with up-to-date land cover mappings to yield a reliable database for evaluation purposes. A statistical analysis and a classification scheme were applied to decide upon the separability of wheat, oat, rye, winter barley, and summer barley.

1 INTRODUCTION

Today, we can identify numerous large to medium scale environmental monitoring approaches, where hyperspectral analysis and remote sensing based quantitative measurements with airborne remote sensing systems can dramatically enhance the significance of spatially explicit information retrieval. The quality of results, however, is not only depending on the algorithms employed for the parameterization of ecologically meaningful variables and processes, but also determined by the information content inherent in the regarding airborne hyperspectral measurements. For this study, experiments have been carried out to support our understanding about spectral variability within similar crops and between different agricultural plots with hyperspectral remote sensing data from the Hyperspectral Mapping System (HyMap).

2 STUDY SITE

The investigated study site is located approximately 10 km east of Trier, Germany, near the border of Luxembourg. With elevation rising from about 130 m above sea level along the Mosel valley to more than 450 m in the Hunsrück area the terrain is a typical low mountain range. On devonic substrates soils are ranging from developed fluvisols along the valley bottoms over dystric cambisols to shallow leptosols on mountain ridges or steep slopes. As the actual peculiarity of soils mainly depends on the agricultural or viticultural use, a great variety of the mentioned soil types can be found. Viticulture is concentrated along steep slopes and in the Mosel valley, with the most favorable areas in Southern aspects. On moderately inclined to flat terrain agriculture is dominating with barley, wheat, oat, rye, and corn being the most prominent crops. Less fertile stands are used as pastures and grassland and cover about 50% of the area under agriculture.

3 MATERIALS

On the 10th of June 1999 several HyMap data sets were acquired over agricultural test sites in the region of Trier. All images have been scaled to radiances ($mW*cm^{-2}*sr^{-1}*\mu m^{-1}$) and were delivered as floating point values. HyMap acquires data with a whiskbroom scanner onto four spectrometers in the wavelength range between 400 and 2500 nm. The spectral range has been covered by 128 bands with bandwidths ranging from 13.7 to 24.3 nm. The signal-to-noise ratio is assumed with values better than 500:1 for all bands (DLR 2000). One image of 512 x 2345 pixels exactly east of

Trier has been selected for the experiments.[1] The data set has been distributed along with positional information derived from differential GPS, attitude data from a mounted IGI system and radiometric calibration settings.
Cadastral information and recent land cover surveys were used as a reference for mapping actual land use (figure 1). All data was gathered in late spring and early summer in order to match image derived information. The data has been stored in a GIS and referenced to the German Gauss-Krüger coordinate system. Additionally, 30 ground control points have been sampled by differentially corrected GPS. A flight synchronous field campaign provided high-resolution spectral reference targets sampled with an ASD Fieldspec II radiometer in the spectral domain between 350 and 2500 nm with 1-nm-resolution.

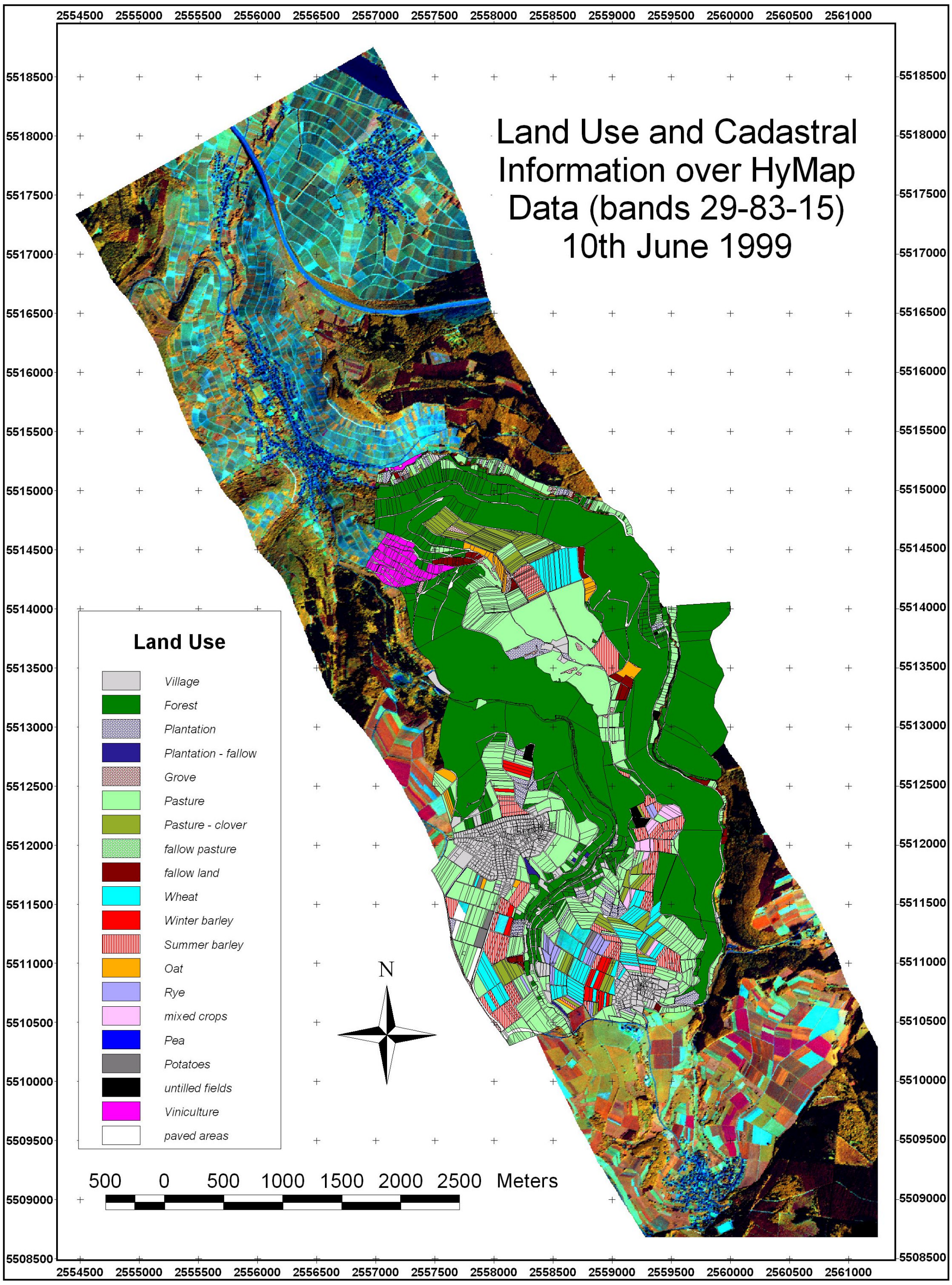


Figure 1: Georeferenced HyMap data, cadastral map, and land cover survey at the time of overpass

[1] A quicklook of the image is available under http://www.op.dlr.de/ne-oe/ir/DAIS/hyeurope1999/990610/FELL.jpg

4 PRE-PROCESSING

To facilitate smooth processing the image was scaled to integer while applying a sensible scaling factor to preserve radiometric accuracy. A thorough radiometric quality check was carried out revealing the following bad band list (table 1). As affected wavelength did not contain essential additional information on the surfaces under investigation, it was decided to eliminate bad bands from further processing rather than pursuing enhancements on deficient bands.

<table>
<tr><th>Band</th><th>Deficiency</th></tr>
<tr><td>1</td><td>strong striping</td></tr>
<tr><td>2</td><td>striping</td></tr>
<tr><td>65</td><td>strong noise</td></tr>
<tr><td>66</td><td>noise</td></tr>
<tr><td>67</td><td>noise</td></tr>
<tr><td>68</td><td>some noise</td></tr>
<tr><td>97</td><td>noise</td></tr>
<tr><td>124</td><td rowspan="5">gradually increasing noise from band 124 (slight) to 128 (strong)</td></tr>
<tr><td>125</td></tr>
<tr><td>126</td></tr>
<tr><td>127</td></tr>
<tr><td>128</td></tr>
</table>

Table 1: HyMap bands of minor quality

Subsequently, an illumination correction was applied to the data set. The flight path was following a South-east North-west direction, resulting in directional illumination differences. A mask excluding dark forest areas and a cloudy patch along the very Southern border of the image was applied during the across-track calculation of a first order polynomial. The resulting band-wise coefficients were applied in a multiplicative manner to account for different reflectance levels.
A parametric geometric correction was performed, incorporating a high resolution digital elevation model, differential GPS derived ground control points, and line-synchronized flight attitude and position data (Schläpfer et al. 2000). Attitude data have been iteratively adjusted for inaccuracies and abrupt shifts due to temporarily insufficient system performance. Final results yielded very high geometric accuracy compared to vectorized large-scale cadastral maps.
Finally, the data set was radiometrically corrected to target reflectance values. Reference targets including lawns, meadows, soils, asphalt, and sport arenas were resampled to the spectral resolution of the HyMap bands and used together with corresponding image derived signatures in an empirical line correction approach.

5 DATA ANALYSIS

The cadastral data base combined with a recent land cover mapping provided an accurate measure of comparing spectral properties in HyMap data for different agricultural land cover types. During the overpass on 10^{th} of June the main crops to be identified in the area under investigation were wheat, rye, oat, summer and winter barley.
As crops and other agricultural products may be spectrally similar or not depending on their phenological stage, growing density and height, or soil background, rather than because of their intrinsic spectral properties, the time of overpass and the geo-ecological setting is equally important as the spectral behavior of the respective vegetative surface. On the 10^{th} of June winter crops have started to change from photosynthetic activity to yellowness already. Contrarily, summer crops were still in a rather photosynthetically active state. However, the challenging environmental setting with crops varying between low and intermediate elevated fields (130 to 350 m) combined with well developed soils in the alluvial areas compared to shallow leptosols on one of the plateaus introduced a great variety of spectral targets.
To determine general spectral properties of different crops a statistical analysis of several targets was carried out first. The objective was to interpret spectral variability for identical and for different agricultural stands. To distinguish between mixed pixels originating from boundary effects and statistical variation from actual intra-field heterogeneity the vector information on land cover classes was buffered. Only the inner polygons have been employed for signature extraction thus excluding boundary pixels.
The second step of the analysis comprised a classification on MNF-transformed data. Only the first 15 bands, selected on the basis of their eigenvalues, were taken into account. An isodata algorithm was employed to automatically separate spectrally distinct classes. To compare classification results and insights from statistical analysis of selected plots the classification scheme was also applied to the selected plots only.

6 RESULTS

The statistical analysis of plots for identical crops clearly indicated differences in albedo, but presented rather homogeneous targets concerning the shape of reflectance spectra (figure 2). Considerable inhomogeneities rather emerged from different environmental settings. Some uncertainties might also be due to some hybrid varieties leading to a different spectral behavior.

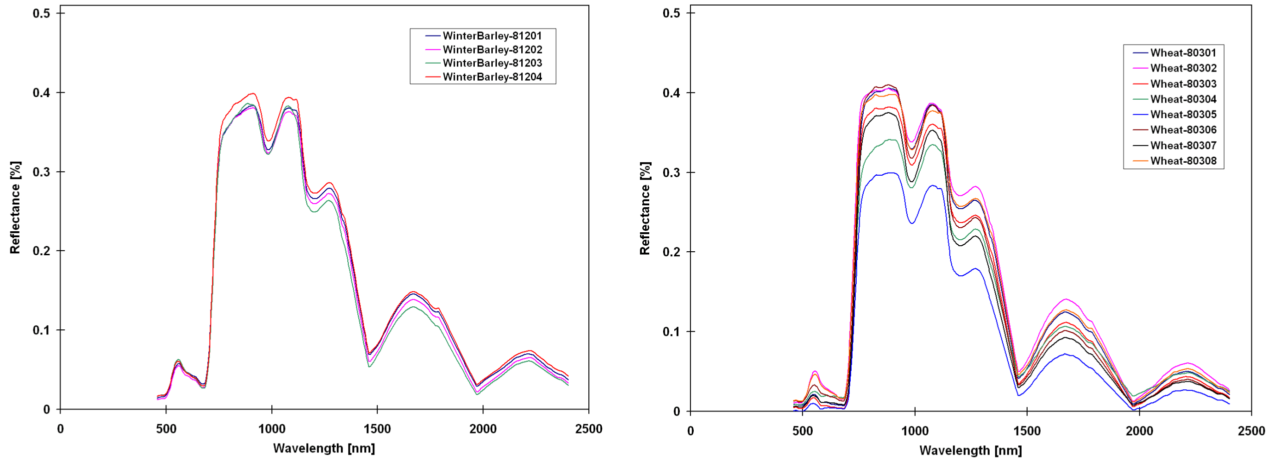


Figure 2: Winter barley and wheat as examples for crops with low and high variance

Differences between plots of the same crop occurred in the visible wavelength domain due to changing levels of photosynthetic activity. Wheat exhibits clear variations, other crops only show minor differences. At the near-IR plateau all crops reveal variations and only winter barley tends to be more or less invariable. As winter barley is the first crop which yellows, it is likely that its invariability can be attributed to the flattening of its spectrum. This is supported by the skewed progression of the spectrum in the near-IR region between 760 and 900 nm (Gilabert et al. 1996). However, the red edge seems to be unaffected and a blue shift is not visible in any spectrum. Wheat and rye show maximum variation in the mid-IR region, which appears rather homogeneous for all other crops. This should be due to changes in plant water content depending on stand properties and local water availability (Guyot 1990).
Compared to different plots of the same crops, where albedo variability is the main variation, spectral differences for miscellaneous species is rather determined by the shape of spectra (figure 3). As albedo is a disturbing factor concerning the objective analysis, a peak normalization was performed generating comparable curves with a relative reflectance maximum at one. After peak normalization it becomes obvious that different crop spectra usually intersect each other, i.e. exhibit different slopes in certain wavelength regions. Especially shifts in shorter wavelengths of the near-IR region seem to affect separability from the spectroscopic point of view.

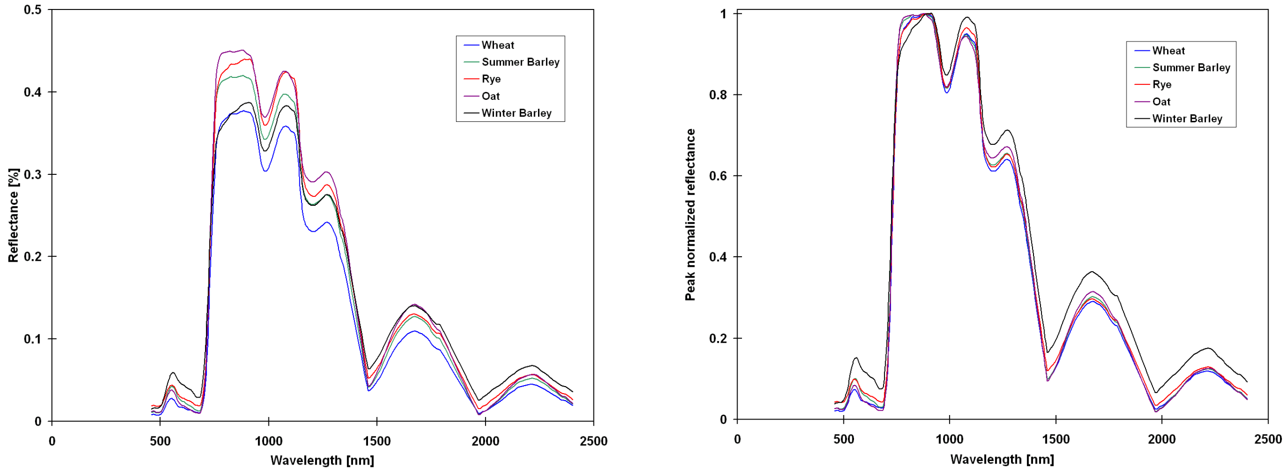
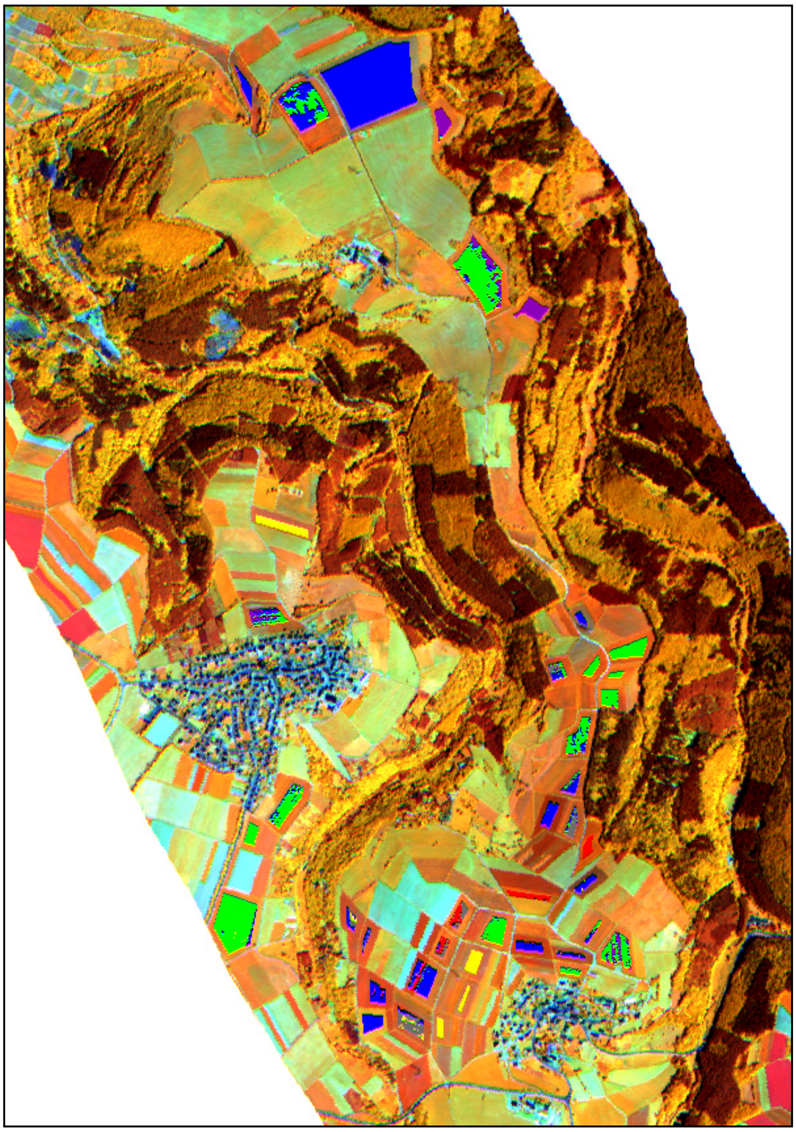


Figure 3: Differences in reflectance for various crops (left), peak normalized (right)

However, even a moderate change in environmental conditions, such as differences in the state of soil (e.g. stoniness, soil water content, etc.) or different terrain elevation resulting in altered climatologic regimes, will certainly yield more divergent spectral signatures than a change in crops (Baret and Jaquemoud 1994, Guyot 1990). This effect is apparent when comparing wheat plots situated in one of the lower valleys and on an elevated plateau. Impact on signatures is of manifold nature, mainly triggered by the change in background reflectance due to the soil properties and related changes in stand density and height; moreover, the plants' intrinsic spectral behavior is changing mainly due to different nutrient and water supply.



The classification produced equally distinguishable classes as spectral interpretation suggested (figure 4). Some variation between plots of the same crop exceeded inter-class variation limits and led to some confusion between these classes. Most fields were correctly classified, with the majority of errors occurring between summer barley and wheat. However, some errors seem to emerge from inaccurate mapping of land cover in the field. Some plots clearly exhibit different cultivations while mapped as one homogeneous crop. Moreover, some plots seem to be affected by introduction of seedlings from neighboring fields. This is clearly visible in areas where crops are growing next to each other, resulting in mutual errors along their borders. Overall separation accuracy between wheat, oat, rye, summer barley and winter barley reached about 85% for pre-stratified data.

Figure 4: Classification over HyMap data.

blue: wheat
red: rye
purple: oat
green: summer barley
yellow: winter barley

7 CONCLUSIONS

Generally, it must be stressed that a mono-temporal remote sensing based identification of different crops is only possible when the time of image acquisition satisfactorily coincides with the respective phenological stages of the crops under investigation. Nevertheless, it seems to be possible to separate wheat, oat, rye, winter and summer barley on the basis of mono-temporal HyMap data with reasonable accuracy. Analysis of HyMap spectra for different plots explained major differences and similarities between the crops under investigation. A subsequent unsupervised classification on stratified imagery led to the same conclusions as the statistical interpretation of image spectra.
In a next step, the concept should be extended to larger areas and a greater variety of targets. While mono-temporal studies will not allow for any desired extension of class separability, a multi-temporal approach will open up higher accuracy regarding phenologically different field crops.

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REFERENCES

Baret F., Jacquemoud S., 1994. Modeling canopy spectral properties to retrieve biophysical and biochemical characteristics. In: Hill J., Mégier J. (eds.), Imaging spectrometry - a tool for environmental observations, Kluwer, Amsterdam, pp. 145-167.

Gilabert M.A., Gandia S., Meliá J., 1996. Analyses of spectral-biophysical relationships for a corn canopy, Remote Sensing of Environment, 55, pp. 11-20.

Guyot G, 1990. Optical properties of vegetation canopies. In: Steven M.D., Clark J.A. (eds.), Applications of remote sensing in agriculture, Butterworths, London, pp. 19-43.

Schläpfer D., Hausold A., Richter R., 2000. A unified approach to parametric geocoding and atmospheric/topographic correction for wide FOV airborne imagery, part 1: parametric ortho-rectification processing, this issue.

German Aerospace Centre (DLR), 2000: Information on the HyMap Hyperspectral Mapping System
http://www.op.dlr.de/dais/hymap/hymap_men.htm (01/07/2000)