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Use of field reflectance data for crop mapping using airborne hyperspectral image

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ABSTRACT

Recent developments in hyperspectral remote sensing technologies enable acquisition of image with high spectral resolution, which is typical to the laboratory or *in situ* reflectance measurements. There has been an increasing interest in the utilization of *in situ* reference reflectance spectra for rapid and repeated mapping of various surface features. Here we examined the prospect of classifying airborne hyperspectral image using field reflectance spectra as the training data for crop mapping. Canopy level field reflectance measurements of some important agricultural crops, i.e. alfalfa, winter barley, winter rape, winter rye, and winter wheat collected during four consecutive growing seasons are used for the classification of a HyMAP image acquired for a separate location by (1) mixture tuned matched filtering (MTMF), (2) spectral feature fitting (SFF), and (3) spectral angle mapper (SAM) methods. In order to answer a general research question "what is the prospect of using independent reference reflectance spectra for image classification", while focussing on the crop classification, the results indicate distinct aspects. On the one hand, field reflectance spectra of winter rape and alfalfa demonstrate excellent crop discrimination and spectral matching with the image across the growing seasons. On the other hand, significant spectral confusion detected among the winter barley, winter rye, and winter wheat rule out the possibility of existence of a meaningful spectral matching between field reflectance spectra and image. While supporting the current notion of "non-existence of characteristic reflectance spectral signatures for vegetation", results indicate that there exist some crops whose spectral signatures are similar to characteristic spectral signatures with possibility of using them in image classification.

1. Introduction

The current suite of high spatial resolution airborne hyperspectral remote sensing systems enable the discrimination and mapping of a number of agricultural crops with precision and accuracy that was not possible before (Whiting et al., 2006; Liang, 2007). The classical method of supervised multispectral image classification that involves training of the chosen classification algorithm has also been the popular choice of hyperspectral image classification methods. The availability and selection of good quality image based training data, which is not a major problem in multispectral image classification, is a major challenge in hyperspectral image classification (Richards and Jia, 2006). With the recent surge in the availability of hyperspectral imaging sensors and sophisticated field spectroradiometers, exploration of the theoretical possibility of using reference field reflectance spectra in image classification process appears appropriate. This idea of using field and laboratory measured reflectance spectra for mapping of various surfaces features has been successfully demonstrated in mineral mapping (Clark and Swayze, 1995; Farrand, 1997; Debba et al., 2005; Kokaly et al., 2008; Swayze et al., 2009), soils classification (Brown, 2007), and to a limited extent in urban materials discrimination (Herold et al., 2004). However, as far as vegetation discrimination is concerned, previous studies have established that there are no spectral signatures, characteristic for a particular vegetation species (Price, 1994; Cochrane, 2000). However, these studies have examined only a limited number of forest vegetation species.

Recent studies indicate the existence of unique spectral reflectance patterns (spectral signatures of materials which are unique during certain growth phase of the materials) for certain vegetation species (Dehaan and Taylor, 2002; Andrew and Ustin, 2006; Nidamanuri et al., 2007; Zomer et al., 2009). A recent study relevant to the question of using field reflectance spectra for image classification is reported by Zomer et al. (2009). They collected field reflectance measurements of wetland vegetation at five sites in California, Texas, and Mississippi and created a common spectral library. This spectral library was used to classify vegetation at a separate location, the Pacheco Creek wetland, California, using a PROBE-1 airborne hyperspectral image. They report a fine discrimination of the wetland vegetation species, though the classification accuracy obtained is not reported explicitly. However, wetland

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vegetation species, when stratified by biome, elevation, or latitude are in limited numbers of species and genera, even considering the world-wide distributions (Zomer et al., 2009). This makes it feasible to develop a functional spectral library for wetland vegetation and assess its potential for image classification (Zomer et al., 2009). Contrary to that, development of spectral library for cultivated vegetation is complicated because of the existence of a large number of potential plant species. In addition, spectral variability is inherent to plant species (Price, 1994; Nidamanuri et al., 2007). Our literature survey reveals that there is a paucity of studies which deal with the idea of transferring field reflectance spectra of cultivated vegetation for hyperspectral image classification.

The objective of this study was to evaluate the possibility of using independent field reflectance spectra as alternative to the image based training data for hyperspectral image classification. Field reflectance measurements of agricultural crops, namely alfalfa (*Medicago sativa*), winter barley (*Hordeum vulgare*), winter rape (*Brassica napus*), winter rye (*Secale cereale*), and winter wheat (*Triticum* spp.) which are collected during four successive growing years (2002–2005) are used for the classification of a historical HyMAP airborne hyperspectral imagery. We believe that the existence of a meaningful spectral relationship between field reflectance spectra and image could open up numerous applications such as rapid crop acreage estimation, monitoring endangered or commercial tree species, characterizing biodiversity and monitoring changes in species composition over time.

2. Materials and methods

2.1. Study site

Spectral data used in this study were collected from two sites located in the northeast Germany. Canopy level hyperspectral reflectance measurements of the crops selected were collected over the experimental plots of the Leibniz-Centre for Agricultural Landscape Research (ZALF) in Muencheberg, Germany. Airborne hyperspectral imagery was acquired for the Dedelow research station of the ZALF which is located 100 km north of the site of field spectral measurements.

The predominant land use categories in the study site were agricultural crops, namely, alfalfa, winter barley, winter rape, winter wheat, and winter rye. The phenology of these crops as captured during the image acquisition was quite variable ranging from main shoot development to fruit development. The extended BBCH scale (Biologische Bundesanstalt, Bundessortenamt and CHemical industry) proposed by Hess et al. (1997) for numerical division of phenological growth stages are used in this study for a better comparison of crop phenology. It describes the entire plant growing stages by numerical values from 00 to 99 with principal growing stages described by numerical values from 0 to 9. A numerical code of 0 indicates germination/sprouting and 9 indicates senescence/harvest. According to this scale, alfalfa was in the flowering stage (scale code of 64 with principal growth stage 6); winter barley was at the main shoot development (scale code of 39 with principal growth stage 3), vegetative propagation/booting (scale code of 49 with principal growth stage 4), and heading (scale code of 51 with principal growth stage 5); winter rape was at the flowering (scale code of 69 with principal growth stage 6), and fruit development (scale code of 75 with principal growth stage 7); winter rye was at main shoot development (scale code of 39 with principal growth stage 3); winter wheat was at tillering (scale code of 29 with principal growth stage 2), main shoot development (scale code of 39 with principal growth stage 3), vegetative propagation/booting (scale code of 45 with principal growth stage 4), heading (scale code of 59 with principal growth stage 5), and flowering (scale code of 60 with principal growth stage 6).

2.2. Spectral data collection and pre-processing

2.2.1. Hyperspectral imagery

Airborne hyperspectral image was acquired on 6 may, 1999 using the HyMAP imaging system with an area extension of 6×10 km along east–west flight lines. The image has a spatial resolution of 5 m and 128 spectral bands with spectral resolution of up to 20 nm. Spectral band configuration of the HyMAP is shown in Table 1. The image was processed to account for radiometric and atmospheric corrections before converting to surface reflectance using the fast line-of-sight atmospheric analysis of spectral hypercubes (FLAASH) atmospheric correction module (Felde et al., 2003). Out of the 128 spectral bands, four spectral bands, i.e. band 1 (403 nm), band 2 (447 nm), band 65 (1410 nm) and band 128 (2480 nm), were eliminated from the analysis because of severe noise and low response of the HyMAP imaging system detector elements in these spectral bands. A false colour of composite (FCC) of the imagery acquired is shown in Fig. 1.

The time difference existed between the acquisition of field reflectance spectra and HyMAP image can be justified based on the fact that, the unique spectral signatures, if in deed exist, should be transferable (portable) across sites. In the absence of portability of unique spectral signatures, the alternative method of collecting spectral signatures every time and for every image acquisition would inevitably undo the apparent advantages of using field reflectance spectra for image classification.

2.2.2. Field spectral measurements

Canopy level spectral reflectance measurements were carried out using FieldSpec JR spectrometer (Analytical Spectral Devices

Table 1
Spectral configuration of the HyMap sensor.

Module	Spectral range (μm)	Bandwidth across module (nm)	Average spectral sampling interval (nm)
VIS	0.45–0.89	15–16	15
NIR	0.89–1.35	15–16	15
SWIR1	1.40–1.80	15–16	13
SWIR2	1.95–2.48	18–20	17

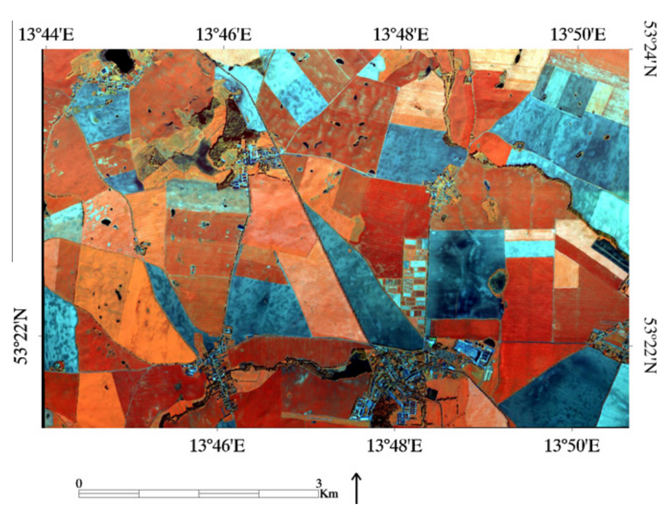

Fig. 1. False colour composite of the hyperspectral image of the study area (spectral channels used: R: 30 (0.868 μm) G: 20 (0.716 μm) B: 10 (0.563 μm)).