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ESTIMATION OF CROP COVER AND CHLOROPHYLL FROM HYPERSPECTRAL REMOTE SENSING

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ABSTRACT

Over the last two decades, there has been extensive development in hyperspectral remote sensing. Interest is rapidly growing in the application of hyperspectral data to precision farming. This paper investigates the potential of hyperspectral remote sensing data for providing crop information for use in precision farming. Ground measurements and airborne hyperspectral Probe-1 data were simultaneously acquired in July 1999 near Clinton, Ontario, Canada. Specifically, percent ground cover and chlorophyll estimations derived from the Probe-1 data are being validated. Constrained linear unmixing was conducted on the airborne hyperspectral surface reflectance and at-sensor radiance data to determine crop endmember fractions. Chlorophyll maps were generated from Probe-1 reflectance data using three different methods. Correlations between ground data and Probe-1 derived image products were significant and produced encouraging results. Although based on a limited range of chlorophyll values available in this study, Probe-1 derived chlorophyll index values were sensitive to differences in SPAD-502 measurements taken in the field. Crop ground cover was significantly correlated with spectral fractions derived from the radiance or the reflectance data.

Introduction

Hyperspectral remote sensing has gone through rapid development over the past two decades. A considerable amount of literature has accumulated in geologic and environmental related applications (Staenz *et al.*, 2000; Lévesque *et al.*, 2000; Nadeau, 2000). Interest is growing in the application of hyperspectral data to precision farming. However, crop growth is very dynamic and monitoring the condition of agricultural crops is challenging. Several studies are underway to investigate the potential of hyperspectral remote sensing data products for use in precision farming, including studies presented by Pacheco *et al*. (2001) and Champagne *et al*. (2001). The objectives of the study discussed in this paper are as follows:

1. To validate crop fraction maps derived from spectral unmixing with percent crop cover estimates;

2. To compare results from unmixing of at-sensor radiance data to results from unmixing of surface reflectance data; and

3. To test several approaches cited in the literature for estimating crop chlorophyll from hyperspectral data and to compare with ground measurements.

Study Site

The study site is located near Clinton, Ontario, Canada (43° 40' N, 81° 30' W). Three corn fields and three bean fields were investigated. Surface cover on these fields included crop vegetation, residue from the previous crop, and soil.

Ground Measurements

Ground measurements were collected from June 24 to July 8, 1999. Approximately ten sampling sites were selected per field to reflect within-field variability, based on elevation and soil maps. Numerous ground measurements were collected during this field campaign. However for this paper, only ground data related to percent ground cover and chlorophyll estimation will be discussed.

Percent ground cover was calculated from vertical photographs taken with a 35 mm camera equipped with a 28 mm lens. The camera was mounted on an overhead mast at a height of 2 m above ground. In this configuration the camera viewed a ground area of 2.3 m^2. Since the Probe-1 data has a pixel size of 5 m by 5 m, photographs were taken 3 to 4 m surrounding the centre of the sample site locations. Three photographs were taken at each sampling in order to obtain percent ground cover of the area covered by a Probe-1 pixel.

Simultaneous with the Probe-1 hyperspectral data acquisition, crop "greenness" was measured using the Minolta SPAD-502 meter. The SPAD-502 measures transmittance of plant leaves in the red and near-infrared spectral regions. The ratio of these two transmittances is proportional to the total leaf chlorophyll content (Boggs *et al*., 1998). At each sampling site, 30 SPAD-502 measurements were collected in a 2-metre area surrounding the centre of each sampling site. These measurements were taken on the plants upper most fully extended leaf. An average of the SPAD-502 measurements was then calculated for each sampling site.

Data Acquisition and Preprocessing

Airborne hyperspectral Probe-1 imagery was acquired on July 7, 1999. The data were collected in 128 spectral bands ranging from 430 nm to 2500 nm. Individual bandwidths at full width of half maximum (FWHM) varies between 13-22 nm with spectral sampling intervals varying from 10-20 nm. The spatial resolution is 5 m by 5 m, resulting in a swath width of 2.5 km (512 pixels).

The raw imagery was first radiometrically calibrated using a reflectance-based vicarious calibration method (Secker *et al*., 2001). Reflectance spectra from a uniform bare soil target were acquired using a GER3700 field spectroradiometer and used with this method to generate a new set of calibrated gains to convert the raw digital numbers (DN) from Probe-1 to radiance. These radiance data were then converted to reflectance using the surface reflectance retrieval procedure in the Imaging Spectrometer Data Analysis System (ISDAS) developed at the Canada Centre for Remote Sensing (Staenz and Williams, 1997).

Methods

<u>Vertical Ground Photograph Classification</u>: The vertical photographs were digitized in three channels (blue, green and red) and processed with

PCI ImageWorks. Unsupervised classification was carried out using ten classes: three classes for soil, three classes for leaf cover, two for residue, one for soil shadow, and one for leaf shadow. These classes were then aggregated to form three major components: leaf cover, residue, and soil. Once the classification was completed, percentages of leaf, soil and residue cover were determined for each photograph. For each of these classes, percent ground cover was then calculated from the average of the three replicate photographs.

Spectral Unmixing: Using the Probe-1 data, constrained linear spectral unmixing was performed using an algorithm implemented in ISDAS (Staenz *et al.*, 1998). Endmember spectra were manually extracted from the image data based on knowledge of the fields. Since the availability of pure pixels under natural field conditions is problematic, pure patches of soil, crop and residue were created. Endmember spectras were then extracted from the canopy within these 20 m by 20 m patches. The patches did not exist on all investigated crops and some endmember spectra from one field were used on the other two fields of the same crop type. Double crop density patches were not "pure" but did constitued about 80% crop and the residue patch did contain a small amount of green grass. However, soil patches were 100% soil. Spectral unmixing was done using the spectral range from 430 nm to 2500 nm. Spectral unmixing was conducted using three endmembers: vegetation (crop), soil and residue. Fraction maps of these endmembers were then derived from the hyperspectral Probe-1 data. Since one of the goals of this study was to assess the necessity of generating reflectance data, the spectral unmixing process described above was completed on both the radiance and the reflectance data sets.

Chlorophyll Estimation: Chlorophyll maps were generated for each field using Probe-1 reflectance data. Three methods were selected from the literature based on their potential for the calculation of chlorophyll maps from hyperspectral data. These three methods generate separate estimates for chlorophyll *a*, *b* and major carotenoid pigments. Since our SPAD-502 field measurements are related to the total chlorophyll content of the plants and since chlorophyll *a* at this stage of plant growth is usually the major contributor to total chlorophyll variability, only chlorophyll *a* and related indices ($PSSR_a$, $PSND_a$) estimates will be reported. The first method is proposed by Chapelle *et al.* (1992) and called the Ratio Analysis of Reflectance Spectra (RARS). In this method, a mean "reference" spectrum from a chlorophyll saturated plant is used to divide each hyperspectral pixel spectra of the image to highlight specific absorption features of chlorophyll *a*, *b* and major carotenoid pigments. For each type of pigment, ratios of amplitude at optimum wavelength extracted from the ratioed spectra mentioned above are used to calculate pigment content from the imagery. The other methods are based on two chlorophyll indices called the Pigment Specific Simple Ratio ($PSSR_a$) and the Pigment Specific Normalized Difference ($PSND_a$) (Blackburn, 1998). The $PSSR_a$ is a simple ratio of reflectance at two optimal wavelengths, in this case 810.4 nm and 676.0 nm for chlorophyll *a*.

$$PSSR_a = R_{810.4} / R_{676.0}$$

$PSND_a$ is a type of normalized index using the same optimal wavelength as $PSSR_a$ for chlorophyll *a*.

$$PSND_a = (R_{810.4} - R_{676.0}) / (R_{810.4} + R_{676.0}).$$

Validation: Crop fractions were correlated with the percentage crop cover estimated from the classified photographs. The chlorophyll content maps were compared with SPAD-502 measurements. For each sampling site, hyperspectral values were averaged on a 3 by 3 pixel window surrounding the centre of the sample site. Correlations were run on data pooled from all bean and corn sites.

Results and Discussion

Spectral Unmixing: A significant correlation was found between the Probe-1 derived image products, and the ground data acquired during the Clinton campaign. The crop fraction of each pixel was derived with a constrained linear unmixing method. These fractions were correlated with the percent crop cover calculated from the vertical ground photographs. A correlation coefficient (R-value) of 0.850 was achieved when the crop fractions derived from unmixing of the radiance data were regressed against percent crop cover from the photographs. In comparison, a coefficient of 0.883 was achieved when the reflectance data were used. These results indicate that spectral unmixing is able to provide information on the extent of crop ground cover. Although correlations are significant, it is clear that some variability is still unexplained. Spectral reflectance from 3-dimensional targets like crop canopies is also dependent upon characteristics of the volume. Thus further analysis is planned to combine several crop measurements into a more robust representation of the crop canopy. The unexplained variance could also be related to limitations in the endmember selection, and this requires further investigation. Endmembers were selected from patches of crop that were not "pure" since crop cover was not complete. In addition, endmembers were extracted from one field, but were used for unmixing on other fields.

Correlation coefficients (0.850 compared to 0.883) were very similar regardless of whether the fraction maps were derived from reflectance data or from radiance data (Figures 1 and 2). This observation suggests that for this particular application, atmospheric correction of hyperspectral data may not be required. For operational near-real time crop monitoring, the elimination of this preprocessing step would be a very significant advantage.

Chlorophyll Estimation: Sample numbers were too small to run correlations between SPAD-502 measurements and chlorophyll estimates on a field-by-field basis. Within one crop type (beans or corn), correlations were weak (R-values less than 0.6) or were non-significant. These poor results are a reflection of the low variability in chlorophyll among sites within one crop type. Although sampling sites were chosen to maximize variability and crop cover did vary among these sites, SPAD-502 values were very similar as reflected in the low standard deviations (Table 1). Thus with only one acquisition date, variability in chlorophyll within one crop class is very limited and is not detected by either the SPAD-502 or the hyperspectral imagery.

Chlorophyll estimates from the Probe-1 imagery were then averaged for each crop type and compared to the average SPAD-502 measurements. These statistics are given in Table 1. On average, SPAD-502 values were higher for the corn crops, and this increase is also observed in the chlorophyll estimates from the Probe-1 imagery. The difference between the chlorophyll estimates for corn and beans was greatest for the $PSSR_a$ chlorophyll index. The greater sensitivity of this index supports the conclusions presented by Blackburn (1998). As concluded by Blackburn (1998), this method seems the most appropriate to estimate plant chlorophyll *a* content per unit area at the canopy level.

The sensitivity of the Probe-1 derived products to differences in chlorophyll between the corn and bean crops indicates that this approach will likely work if variability exists. However these approaches need to be tested on a multi-temporal data set, where greater variability is probable, or in a field campaign where chlorophyll variability is induced.

	White Beans		**Corn**		***Difference between means***
	Mean	***Std. Dev.***	**Mean**	***Std. Dev.***	
SPAD	**42.18**	*1.66*	**58.37**	*2.79*	*16.19*
RARS	**9.85**	*0.78*	**11.86**	*0.54*	*2.01*
PSNDa	**0.49**	*0.05*	**0.75**	*0.13*	*0.26*
PSSRa	**3.04**	*0.46*	**10.23**	*1.11*	*7.19*

Table 1. Comparison Between Chlorophyll Estimates Derived From PROBE-1 and SPAD-502 Measurements.

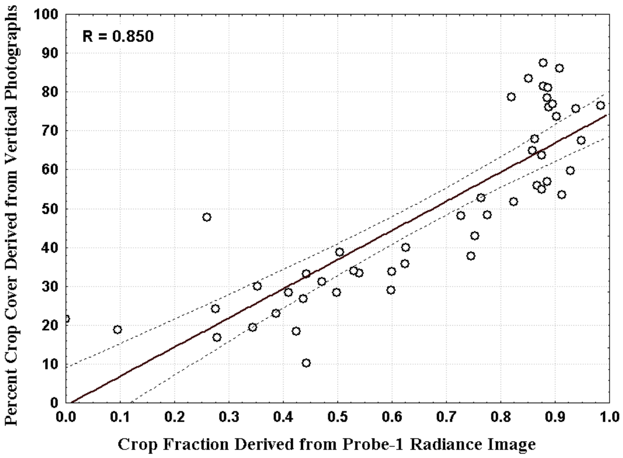

Figure 1. The correlation between crop fractions derived from Probe-1 radiance data and percent crop cover derived from vertical photographs.

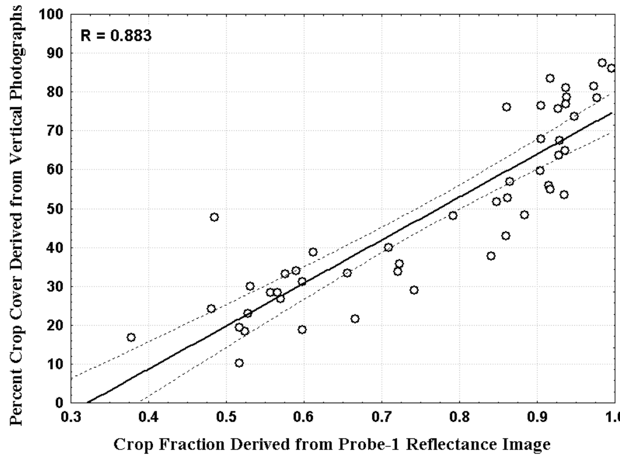

Figure 2. The correlation between crop fractions derived from Probe-1 reflectance data and percent crop cover derived from vertical photographs.

Conclusions

In 1999, Probe-1 imagery was acquired over several corn and bean fields. Crop fraction and chlorophyll maps were generated from these hyperspectral data cubes. Validation of these map products using ground data indicated that crop fractions derived from spectral unmixing were significantly correlated with percent crop cover. Comparable results were obtained using either radiance or reflectance images. Thus atmospheric correction may not be required for generating crop fraction maps, and without this preprocessing step, the turnaround time for operational crop monitoring could be reduced. Differences in the "greenness" values measured using the Minolta SPAD-502 meter are reflected in differences in the chlorophyll values derived from the Probe-1 imagery. However, variability in canopy chlorophyll within a crop type was small. Thus these methods must be tested on a more extensive data set. Nevertheless, these initial results are encouraging and further analysis using these methods is being planned.

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References

Blackburn, G.A. (1998), “Quantifying Chlorophylls and Carotenoids at Leaf and Canopy Scales: An evaluation of Some Hyperspectral Approaches”. *Remote Sensing of Environment*, **66**:273-285

Boggs, J., Tsegaye, T., Fahsi, A. and T. Coleman (1998), "Assessment of Plant Nitrogen Content Using a Chlorophyll SPAD Meter and Ground Truth Data (Part I)". *First International Conference: Geospatial Information in Agriculture and Forestry*, Orlando, June 1-3, 1998, **2**:555-559.

Champagne, C., Staenz, K., Bannari, A., Deguise, J.-C. and H. McNairn (2001), "Validation of a Hyperspectral Curve-Fitting Technique for Mapping Crop Water Status". (Submitted to the *23rd Canadian Symposium on Remote Sensing*, August 21-24).

Chapelle, E.W., Kim, M.S. and J.E. McMurtrey III (1992), "Ratio Analysis of Reflectance Spectra (RARS): An Algorithm for the Remote Estimation of the Concentration of Chlorophyll A, Chlorophyll B, and Carotenoids in Soybean Leaves". *Remote Sensing of Environment*, **39**:239-247.

Lévesque, J., Staenz, K. and T. Szeredi (2000), "The Impact of Spectral Band Characteristics on Unmixing of casi Data for Monitoring Mine Tailings Site Rehabilitation", *Canadian Journal of Remote Sensing*, **26**(3):231-240.

Nadeau, C. (2000), "Analyse des effets atmosphériques dans les données en télédétection du moyen infrarouge sur la classification des minéraux de surface en milieu aride", Université de Sherbrooke, Département de Géographie et Télédétection, 99 pages.

Pacheco, A., Bannari. A., Deguise, J.-C., McNairn, H. and K. Staenz (2001), "Application of Hyperspectral Remote Sensing for the LAI Estimation in Precision Farming". (Submitted to the *23rd Canadian Symposium on Remote Sensing*, August 21-24).

Secker. J., Staenz, K., Gauthier, R.P. and B. Budkewitsch (2001), "Vicarious calibration of airborne hyperspectral sensors in operational environments", *Remote Sensing of Environment*, **76**:81-92.

Staenz, K. and D.J. Williams (1997), "Retrieval of Surface Reflectance from Hyperspectral Data Using a Look-Up Table Approach". *Canadian Journal of Remote Sensing*, **23**(4): 354-368.

Staenz, K., Szeredi, T. and J. Schwarz (1998), "ISDAS - A System for Processing/Analyzing Hyperspectral Data". Technical Note, *Canadian Journal of Remote Sensing*, **24**(2): 99-113.

Staenz, K., Nadeau, C., Secker, J. and P. Budkewitsch (2000), "Spectral Unmixing Applied to Vegetated Environments in the Canadian Arctic for Mineral Mapping", *Proceedings of XIX ISPRS Congress*, Amsterdam, The Netherlands, July 15-23, 8 p.