INITIAL VEGETATION SPECIES AND SENESCENCE/STRESS INDICATOR MAPPING IN THE SAN LUIS VALLEY, COLORADO USING IMAGING SPECTROMETER DATA

By
Roger N. Clark, Trude V.V. King, Cathy Ager and Gregg A. Swayze
U. S. Geological Survey
Mail Stop 964
Box 25046 Federal Center
Denver, CO 80225

INTRODUCTION

Vegetation covers a large portion of the Earth's land surface. Obtaining quantitative information about vegetation with remote sensing has proven difficult. To first order, all vegetation is chemically similar, and most healthy plants are green showing absorption bands that are almost identical. Plant species are generally characterized by the leaf and flower or fruit morphology, not by remote sensing spectral signatures. However, to the human eye, many plants show varying shades of green, so there is direct evidence for spectral differences between plant types. Quantifying these subtle differences in a predictable manner has not been easy, and has been made more difficult by lack of adequate instrumentation.

Clark *et al.*, (1990a, 1991) developed a new analysis algorithm that uses a digital spectral library of known materials and a fast, modified-least-squares method of determining if a single spectral feature for a given material is present. This algorithm, now called "tricorder," compares continuum-removed spectral features (Clark and Roush, 1984) from the imaging spectrometer data set to corresponding continuum-removed spectral features from a reference spectral library. Multiple features from multiple materials are compared and the closest match is selected. The algorithm does not force a detection like many other algorithms. For example, many algorithms take a set of curves and best fit them to the observed data, often requiring a set of parameters (like mineral fraction) to sum to one. The tricorder algorithm has no such constraint. If the materials do not exist in a given pixel, such that there are no spectral features from those or similar materials, the algorithm produces zeros, indicating they are not detected.

The human eye sees different plant leaves as shades of green, as characterized by the "green peak" in reflectance spectra. The eye/brain color system differentiates shades of green under different lighting conditions. For example, under indoor incandescent light, there is a strong red slope to the spectral signal received by the eye due to the red spectral shape of the light source (as compared to the same plant in direct sunlight). We are still able to distinguish the plant as green and distinguish different plants as various shades of green.

The tricorder algorithm is very sensitive to the shape of spectral features and has the potential to distinguish more subtle differences in the visible spectrum of plants than the human eye. We have applied this method, along with reference spectra of specific plants, to map vegetation species in AVIRIS scenes.

The continuum removal to isolate diagnostic spectral features is an important step, particularly when a pixel contains spectral information from green plants, dry vegetation, and soil. In such a case, the combination of materials within a pixel changes the color perceived by the human eye. However, by isolating absorption features with continuum removal, the position and shape of the continuum removed spectral feature remains constant, although its depth changes with absorber fractional areal coverage in the pixel. The tricorder algorithm normalizes the absorptions so that overall shape is compared.

IMAGING SPECTROMETER DATA

We analyzed AVIRIS data obtained over agricultural areas in the San Luis Valley of Colorado. The data were acquired on September 3, 1993. A combined method of radiative transfer modeling and ground calibration site reflectance was used to correct the flight data to surface reflectance (Clark *et al.*, 1994a). This method, called Radiative Transfer Ground Calibration, or RTGC, corrects for variable water vapor in the atmosphere and produces spectra free of artifacts with spectral channel to channel noise approaching the signal to noise of the raw data. The calibration site soil samples were obtained on the day of the overflight and measured on our laboratory spectrometer

(Clark *et al*, 1990b). The site was near the center of the AVIRIS scene and the spectra of the soil is spectrally bland, especially in the region of the chlorophyll absorption in the visible portion of the spectrum.

The center of the scene is located at approximately 106° 03' longitude, 37° 23' latitude, and the scene covers about 92 square kilometers. This scene is one of 28 in the area for a general project to study the Summitville abandoned mine site, located in the mountains west of the San Luis Valley, and its effects on the surrounding environment.

VEGETATION SPECIES AND REFERENCE SPECTRA

The study area includes farmland producing potatoes, alfalfa, barley, oat hay, canola, and open fields containing chico, and other unidentified weeds. Ideally, one would have a digital spectral library of reference spectra of the plant species to be mapped. Such a library does not exist for vegetation, as it does for minerals (e.g. Clark *et al.*, 1993b). It is not known how many spectra as a function of growing season would be required to represent the changing spectral signatures of plants.

Some plant species were measured with a portable field spectrometer, but due to windy conditions and limited availability of the instrument, sufficient data to form a library of all crops could not be obtained. The main objective of the field operations was to provide spectral information on sites with detailed geochemical analysis. Because of the limitation of obtaining field spectra, reference spectra were obtained for sites of known species directly from the AVIRIS data. AVIRIS, having been well calibrated to surface reflectance, is an excellent field spectrometer, providing data for large areas. The alfalfa, canola, oat hay, and nugget potato spectra show the plants to be green and healthy. The barley had lost all its chlorophyll signature. The Norkotah potatoes were not being irrigated as they were about to be harvested, and consequently they showed weak chlorophyll and cellulose absorptions with soil (clay) absorptions from exposed soil. These potatoes were also being sprayed with a defoliant. Thus, they should show decreased chlorophyll absorption along with a shift of the red edge of the absorption to shorter wavelengths. The chico and pasture spectra show combinations of chlorophyll and cellulose (dry vegetation) absorptions. There was rain in the valley in the few days before the flight so the chico/pasture may not show much water deprivation stress (being native plants they are hardy and can also withstand some reduced precipitation compared to the crops).

TRICORDER ANALYSIS

The continuum-removed chlorophyll-containing spectra are shown in Figure 1. The shape differences between each species enable the tricorder algorithm to discriminate between them. The tricorder algorithm produced maps of the distribution of each material. If there are other plants present in the image with similar spectral features, they could be misidentified as one of those in set of spectra used in the mapping. Thus, it is important to have a complete set of reference spectra. The extensive work by many workers on the Summitville project provided knowledge of the crops in the area, thus our spectral library for this case should be complete for crops. As the time of data acquisition was early fall for this mountain valley (elevation ~7650 feet, 2330 meters), some crops and/or pasture were senescing. Since the crops were changing spectrally, it was not known how representative a single reference spectrum for each crop would be. Each crop exists in several fields, each of which may have been in a different stage of senescence.

The tricorder algorithm examines the spectrum of each pixel in the image and chooses the best match to the set of reference spectra. The images from each crop/soil/pasture match were then color coded and a color coded map produced (AVIRIS Workshop Slide 1). Results of field checking of crops in the area were used to produce a color coded answer map for comparison. Field verification data was supplied by Maya ter Kuile of Argo Engineering (1993, personal communication), and our own work. Every crop and field could not be checked due to limited resources for this large area.

Examination of the results shows the tricorder-derived map to be highly accurate. Of 43 verification fields (not including chico/pasture), 7 included the sites of our reference spectra, 33 were identified correctly, another 3 were identified as mixed by the tricorder analysis (but were indicated as one crop type in the field data), and no fields were incorrect. The fields identified as mixed were of two species, one of which was correct in each case. The field check was done by driving the roads and identifying the crops visually. Because of the time required to develop this analysis (AVIRIS data receipt followed by calibration to surface reflectance in January, 1994, initial mapping in February, 1994), and the fact that it was winter, we were unable to investigate the cause of the discrepancies in the three fields mapped as mixed. If we give a score of half to the three fields identified as mixed,

the success score of 96% shows the method is accurate.

The accuracy is made even more impressive when one considers several fields were mapped correctly even though they had already been harvested. There was apparently enough plant material still left on the fields to still make a correct identification. This is again possible because the algorithm normalizes the absorptions, so even though the vegetation cover may be only a few percent, a correct identification can be made. The harvested areas can be identified in the data as circular plots where the colored pixels are sparse and/or low in intensity. Clark *et al.*, (1992) was also able to differentiate vegetation communities on the arid Colorado Plateau, another sparsely vegetated case. The harvested areas should also be under stress, and are indicated as such in the senescence/stress map.

Canola was mapped in many of the areas known to be pasture. While it is possible that canola seeds have been blown into surrounding fields and are growing, it is more likely that the canola spectral signature is close to other (native?) plants in those open fields. Complete discrimination of crops and surrounding wild vegetation requires a more complete set of reference spectra, beyond the scope of this initial study.

SENESCENCE/STRESS MAPPING

The long-wavelength side of the chlorophyll absorption (~0.68 to ~0.73 μm) forms one of the most extreme slopes found in spectra of naturally occurring common materials, plant or mineral. The absorption is usually very intense, ranging from a reflectance low of less than 5% (near 0.68 μm) to a near infrared reflectance maximum of ~50% or more at ~0.73 μm). The properties of reflectance spectra (e.g. Clark and Roush, 1984) indicate such an absorption band is "saturated." In such a case, the absorption band minimum will not change much with increased or decreased absorption, but the wings of the absorption will change. When the chlorophyll absorption in the plant decreases, the overall width of the absorption band decreases. The short wavelength side of the chlorophyll absorption is not observed in reflectance like that of the long wavelength side, because of other absorptions in the ultraviolet (UV). The result of this combination appears as a shift to shorter wavelengths as the chlorophyll absorption decreases. This has popularly become known as the "red-edge shift" or the "blue shift of the red edge" and can be caused by natural senescence, water deprivation, or toxic materials (e.g. Collins *et al.*, 1983; Rock *et al.*, 1986).

The ratio of two spectra, one shifted in wavelength, the other not, and each with steep slopes as seen at the "red edge," will produce a spurious feature when there is only a small shift between the two. If the blue shifted spectrum is divided by an unshifted spectrum, a peak will be observed in the ratio. For a spectrum of green vegetation, a 1 nm shift will produce a residual feature of about 6%. The AVIRIS data have a signal to noise of several hundred in this spectral region, so red-edge shifts of less than 0.1 nm are possible to detect. We used field spectrometer spectra for the San Luis data set, and computed a ratio cube which would show a peak when a shift occurs.

The red-edge shift was mapped using the tricorder algorithm. The fact that the resulting image shows no horizontal scan line striping attests to the superb wavelength stability of the AVIRIS instrument. As indicated earlier, the senescence/stress crop fields are those which have been harvested, sprayed with a defoliant, deprived of water, or may have other toxic influences. The area covered by this scene is not affected by acid mine drainage from the Summitville mine, thus it provides a control for the region of what might be expected under normal agricultural conditions.

CONCLUSIONS

Vegetation species mapping is possible with high precision using spectral feature analysis of data from airborne imaging spectrometers. Once calibrated, and after reference spectra have been selected, species mapping, along with senescence/stress indicator mapping can be achieved in less than 1 second of CPU time per square kilometer per species (or soil/mineral) on a 10 million floating point operation per second (MFLOP) workstation.

Imaging spectroscopy data can be used for environmental application, monitoring vegetation cover and its health, monitoring vegetation species, and providing a rapid overview of large areas. When applied to large areas, the cost to derive these maps is low in cost relative to field checking and monitoring on the ground. The species maps might be used for more accurate crop yield predictions.

Space limitations prevent us from presenting the entire AVIRIS data set of the Summitville and San Luis Valley study area in this paper, and processing is not yet complete. Additional areas, including vegetation species and senescence/stress indicator maps for more of the study area will be shown at the meeting.

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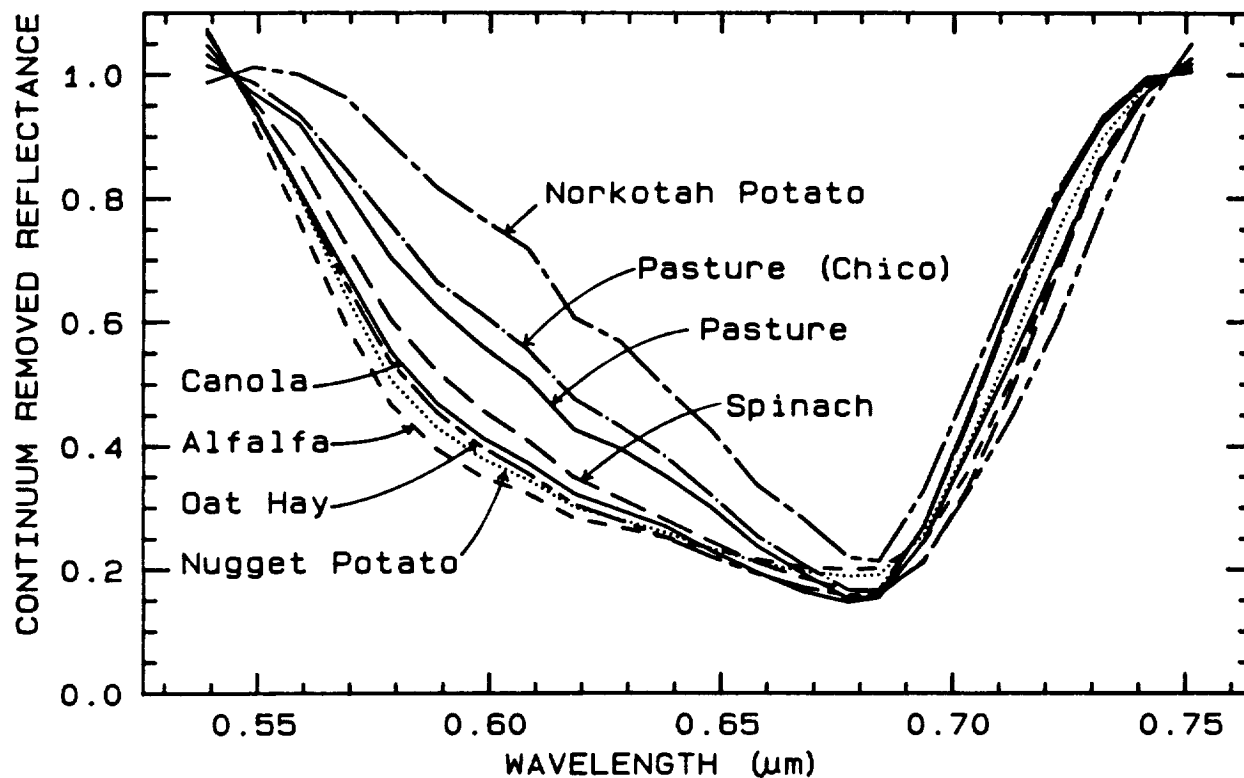
Figure 1. The continuum-removed chlorophyll absorption spectra are compared. Note the subtle changes in the shapes of the absorption between species.