KNOWLEDGE-BASED IMAGING SPECTROMETER ANALYSIS AND GIS FOR FORESTRY

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Abstract — **In 1993 and 1994, AVIRIS images were taken by NASA's ER-2 over test sites in British Columbia as part of the SEIDAM (System of Experts for Intelligent Data Management) project. To support these acquisitions, extensive ground measurements were made including calibration with ground-based spectrometers and uniform targets. A method for calibration of the AVIRIS sensor has been developed which uses these ground spectra and a JPL-modified MODTRAN 2 radiative transfer model. The ingest, calibration and geocoding of AVIRIS imagery is a sophisticated task for which expert systems have been constructed. The geocoded AVIRIS imagery are interfaced to a GIS and attribute data base. Expert systems generate spectral end member images, atmospheric images, band moment images, and principal component images. SEIDAM contains a meta data database for imagery and GIS files. The system uses case-based methods to solve user-specified goals and product selection. In analyzing AVIRIS imagery, SEIDAM follows the analysis paths which a domain expert has taught it or selects alternative paths based on similar training cases. SEIDAM controls the image analysis software, the GIS software, and the database software. Analysis results are available as GIS file updates, tables, images, or visualizations. SEIDAM uses an expert system shell written in Prolog and runs on a SUN computer. It controls software on SUN, SGI, and VAX computers. This paper will describe the expert system methodology and the AVIRIS examples for scenes over the 15 km by 23 km Greater Victoria watershed test site.**

I. INTRODUCTION

As part of NASA's Applied Information Systems Research Program, a project is being conducted to create an intelligent system (SEIDAM) which manages and integrates remote sensing data from aircraft and satellites with multiple geographic information systems in order to respond to queries about the forests and the environment. In the summers of 1993 and 1994 aircraft and satellite acquisitions took place over three test sites in British Columbia (Greater Victoria Water District (GVWD), Tofino Creek, and Parson). These flights included the use of imaging spectrometers, the most important of which was JPL's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) sensor. The imaging spectrometer data were acquired by NASA using an ER-2 at an altitude of approximately 20 km and were subsequently radiometrically, spectrally and geometrically corrected for sensor characteristics at JPL. Approximately six gigabytes of AVIRIS data were acquired during this campaign.

In order to facilitate the laboratory wavelength and radiometric calibration of the AVIRIS data to reflectance, ground reflectance measurements of certain selected light and dark targets were carried out using a GER Mark II spectrometer, at times in close proximity with the ER-2 overflights of the GVWD test site. The complexity of the calibration process, which included the running of a sophisticated atmospheric correction model, made it necessary to create expert systems which would contain the domain knowledge of the calibration and data preparation processes, and thus permit rapid processing and analysis of the data.

II. AVIRIS CALIBRATION AND DATA PREPARATION

Figure 1 is a diagram of the SEIDAM concept [1]. SEIDAM controls software distributed across a computer network. For example, the image analysis software used for AVIRIS includes PCI on a SGI IRIS workstation, ENVI on a SUN workstation, and LDIAS on a VAX. The GIS used for the AVIRIS expert systems is ESRI ARC/Info.

A) AVIRIS Calibration

The 1993 AVIRIS data were calibrated using the mean radiance spectrum from the GVWD data set from 1993. Key atmospheric absorption features were identified due to water vapor at 720, 820 and 940 nanometres. Oxygen absorption at 760 nm, and Carbon Dioxide absorption at 1450, 1601 and 2005 nm were also identified. All AVIRIS data were found to be consistent with the above mentioned absorption features, with no inconsistencies in the wavelength calibration.

Atmospheric corrections to the AVIRIS data were carried out using the MODTRAN II model [2] as modified by JPL [3]. The radiometric calibration for atmospheric absorption and scattering of each of the four AVIRIS spectrometers was determined using the MODTRAN II results.

The MODTRAN II model was tuned to a single ground target for which ground spectral measurements had been

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made. The atmospherically corrected AVIRIS radiance was compared against the ground target. The differences between the corrected AVIRIS data and the ground measurements were used to create a function, a forced-fit function, which represented a combination of sensor corrections and residual atmospheric corrections. A gravel target with published spectra was used for creation of the forced-fit functions beyond 850 nm, due in part, to the unavailability of field spectrometer data in this wavelength regime at the time of the overflight.

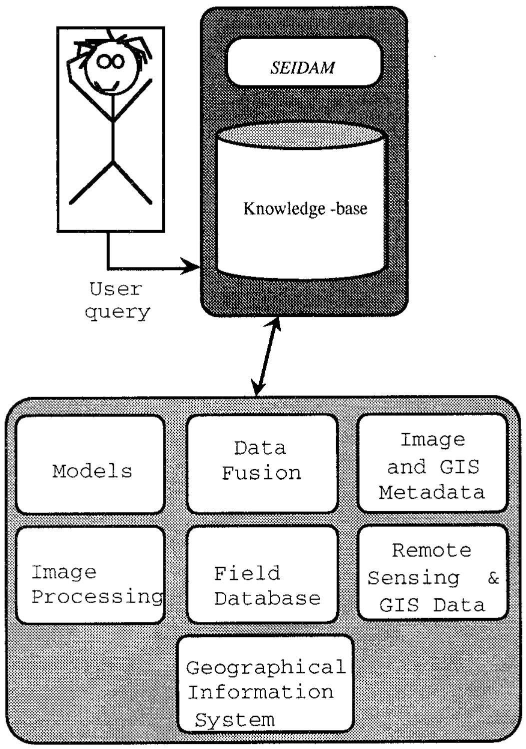

Figure 1. Conceptual view of the SEIDAM system

The effects of atmospheric water vapor beyond 1000 nm wavelength regime were minimized using a regression technique for which it was assumed that no leaf water effects, or atmospheric water effects were present over the gravel target. The results indicated an agreement between the corrected AVIRIS data and the MODTRAN model of better than 1%. This result indicated that the default, mid-latitude summer atmospheric model of MODTRAN was quite adequate for wavelengths beyond 850 nm.

With subsequent AVIRIS scenes over the GVWD, atmospheric correction could be carried out using MODTRAN II and the forced-fit function derived from the ground calibration described previously. AVIRIS calibration was also carried out for the Tofino Creek scenes and it was found that the forced-fit function derived at the GVWD test site remained valid. The MODTRAN II parameters were adjusted to reflect the atmospheric conditions at Tofino at the time of overflight.

B) Analysis of AVIRIS Data

Remotely sensed data from instruments such as AVIRIS require complex analysis techniques and algorithms to fully utilize the hyperspectral nature of the data. Some of the techniques used to analyze AVIRIS data include spectral endmember analysis techniques and band-moment analysis techniques to reduce the vast dimensionality of AVIRIS data. An advantage of using endmember analysis of AVIRIS data is that once a spectral reference library is available for a particular application, then the endmember technique can be applied for identifying objects in AVIRIS imagery.

Another analysis technique used for AVIRIS data was band-moment analysis. Band moment analysis also reduces the dimensionality of hyperspectral data by computing higher order statistical moments over the spectrum. By computing the band moments and applying classical feature selection to these moments, the result yields an image with high information content with three features, as shown in Figure 2. Band-moment analysis requires substantially less computing time compared with classical discriminant analysis. Following feature selection, we apply segmentation algorithms to the band-moment analysis data. Applying segmentation to data which include edge components from all wavelengths enables the structural units of the image to be more easily identified. Shown in Figure 3 are results of segmentation performed on the band-moment analysis image. Four moments were used for this analysis: mean, standard deviation, skewness and kertosis. These four moments were subjected to segmentation with gradients being computed using a variance operator and a three by three-pixel window. The classifier was trained by an operator and each segment was classified.

Figure 3 shows that the major clear-cuts are correctly identified by the segmentation process and appear as a white theme in the image. The degree of accuracy with which the clear-cuts are identified using the band-moment analysis image is dramatic. Note that even small changes in the forest cover, which are of the order of ten pixels in dimension, are correctly segmented.

This sequence of data preparation, calibration, and analysis was incorporated into expert systems as described in the next section.

III. AVIRIS EXPERT SYSTEMS

The SEIDAM system relies on several artificial intelligence approaches to solve complex problems. *Software agents* (also known as *apprentices* [4, 5] and *softbots* [6]: systems that unobtrusively observe the

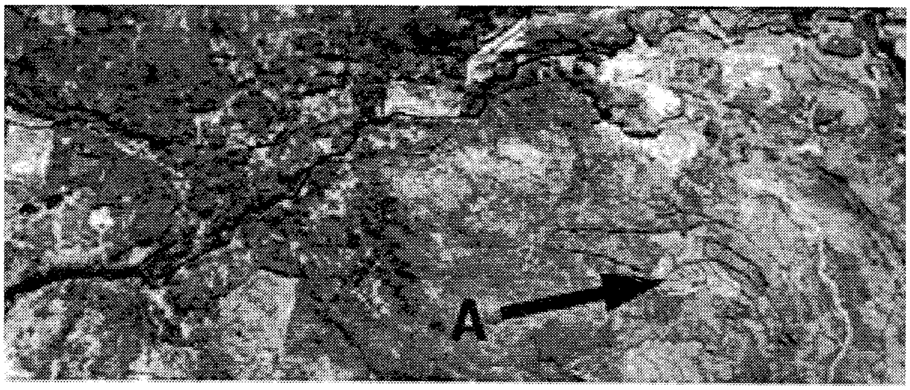

Figure 2: Band-moment reflectance image based on mean, standard deviation and skewness. Note the details within the clear-cuts due to regeneration. Note clear-cut labeled as "A" prior to segmentation.

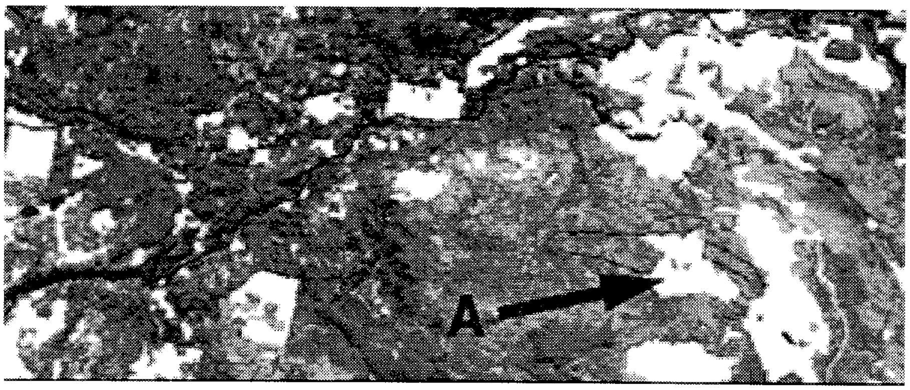

Figure 3: Major clear-cuts are correctly identified through the segmentation process. The segmented clear-cuts are shown in white. The clear-cut labeled as "A" in Figure 2 is highlighted.

manner in which they are used, adapt to the tasks for which they are used, as well as learn from the circumstances of their use) are the first type of AI tool used in SEIDAM and their purpose is to perform low level tasks such as preparing data directories, creating optical models or calibrating AVIRIS imagery. Each agent, Figure 4, is composed of four different components: a rule-based expert system, a frame-based knowledge-base, a suite of third party software packages, and a set of command operators that are used to send instructions to the third party software. The AVIRIS calibration agent, for instance, uses a program called *calib* to create a slope-intercept model from a filtered optical model that is fed to another program called *calibrate* along with an input AVIRIS image and results in a calibrated AVIRIS image. The expert system for this agent will query its knowledge base for the parameters to perform the calibration and provide them to the *calib* and *calibrate* programs via the command operators.

Each agent can provide a description of the task it can perform in the form of a STRIPS-like [7] planning operator. In turn, these operators can be used by a problem solver (planner) [8] called PALERMO (**P**lanning **A**nd **LE**arning for **R**esource **M**anagement and **O**rganization), the second AI approach in SEIDAM, to create plans. A plan indicates what agents should be used to solve complex tasks, and the order in which they must be activated. For the AVIRIS imagery calibration problem, seven agents are used to perform the processing. In order, they are: a signal to noise agent, an optical model agent, a plot optical model agent, a convolve output agent, a calibrate agent, a moment radiance agent and a moment reflectance agent.

The signal to noise agent calculates the signal to noise ratio. The optical model agent determines the characteristics of the atmosphere up to a given height. The characteristics are calculated twice, the first time with 0% reflectance and the second time with 10% reflectance. The plot optical model agent plots both the 0% and 10% reflectance on the same graph. The convolve output agent convolves radio sonde data using a Gaussian function to produce output which matches AVIRIS wavelengths. The calibrate agent calibrates AVIRIS data from raw radiance values to reflectance values. The moments radiance agent computes the mean, standard deviation, skew, and kertosis from the raw AVIRIS image with 10% atmosphere. Finally, the moments reflectance agent calculates the mean, standard deviation, skew, and kertosis from the raw image with 0% atmosphere. Channels in which the ground is obscured by the atmosphere are not included.

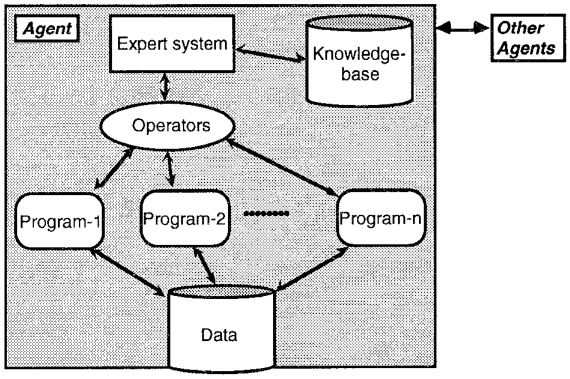

Figure 4 - A software agent.

The problem solver is a case-based reasoning (CBR) system that uses derivational analogy [9, 10] and transformational analogy [9, 11]. The search mechanism used for the derivational analogy component is goal-regression. A case is represented as a triple (<goal>, <preconditions>, <plan>) where <goal> is the expression representing the user's goal, <preconditions> represents the conditions under which the case is applicable and <plan> is the sequence of agents that must be executed to satisfy the user's goal. When a CBR system is presented with a problem to solve, it will check its case-base to find an existing solution to a past problem where the goal satisfied by the past problem is similar to the goal from the new problem. There are several approaches to establishing similarity. The approach taken in PALERMO is to declare two goals similar if they differ only in subterms of their expressions (e.g.: map_sheet(092b042, location, 'Greater Victoria Watershed') and map_sheet(092F023, location, 'Tofino Creek') are similar whereas map_sheet(092b042, location, 'Greater Victoria Watershed') and aviris_image(PG01512-1.bil_image, location, 'Greater Victoria Watershed') are not). PALERMO will retrieve a case and make the modifications to adapt it to the new problem.

If the modified case does not violate any constraints expressed in the agent descriptions, then it is generalized by using machine learning techniques and stored in the knowledge base for future use.

IV. CONCLUSIONS

This paper has described an intelligent system for calibrating AVIRIS imaging spectrometer data for atmospheric effects and for creating imagery with enhanced information content. An example of automated detection of clear-cuts with AVIRIS segmentation is shown. The method of creating agents with PAROT has been presented. Six expert systems have been linked to create this system which simplifies the use of 224-channel AVIRIS imagery.

V. ACKNOWLEDGMENTS

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