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Hyperspectral Imagery: A New Tool For Wetlands Monitoring/Analyses

PURPOSE: This technical note describes the spectral and spatial characteristics of hyperspectral data and the potential application of these data for wetlands studies and monitoring applications. The advantages and disadvantages of these data for wetland evaluations are discussed. Spectral signatures extracted from data acquired by NASA's collected Airborne Visible/Infrared Imagery Spectrometer (AVIRIS) hyperspectral scanning over a wetland study site are analyzed.

BACKGROUND: Remote sensing technology is an important tool for exploring, monitoring, and analyzing wetland systems. Researchers have explored the use of digital imagery acquired from aircraft and spaceborne platforms for mapping wetlands and for analyzing changes to wetland systems (Lampman, 1992). However, traditional digital imagery from multispectral scanners is subject to limitations of spatial and spectral resolution.

- Spatial resolution refers to the size of individual picture elements or the area of the surface imaged in each of the square elements which compose the image. Spatial resolution is usually measured in meters. Typically, sensors such as the Thematic Mapper (TM) carried on the Landsat series of satellites have a spatial resolution of approximately 30 by 30 m. In other words, a feature must be fairly large and homogenous in nature in order to be detectable in an image.

- Spectral resolution refers to the number and width of the portions of the electromagnetic spectrum measured by a sensor. Multispectral scanners measure the radiation reflected by surface features in several portions of the spectrum and convert these analog measurements into digital counts, usually representing an 8-bit (0-255) range. By using statistical methods to analyze the distinct way in which different surface features reflect radiation in different parts of the spectrum, it is possible to characterize the surface features which make up an area. When the radiation reflected by a surface feature is only measured in 4-10 broad portions of the spectrum (which is typical of traditional multispectral sensors), it is sometimes difficult to differentiate between surface cover types which are similar in nature (such as wetland flora), or to detect subtle changes in the cover types of interest. The broad nature of the spectral wavebands acts to mask the subtle differences in spectral response of like cover types. When the spectral and spatial limitations of multispectral scanners are considered in concert, one can begin to appreciate the difficulties in using data from these sensors for mapping and analyzing areas as complex as wetlands.

A new type of remote sensing scanner is now being produced which, unlike multispectral scanners, is capable of measuring up to 250 very narrow portions of the spectrum. The systems are referred to as "hyperspectral sensors." They promise to revolutionize the utility of remotely sensed data for mapping and monitoring wetlands by eliminating the prior limitations of spectral resolution. With hyperspectral sensors it may be possible to map individual wetland plant species, as well as to detect very subtle changes in wetland systems, such as early signs of stress. Despite the great promise they offer, these sensors also introduce a suite of problems which must be addressed before it will be possible to routinely use these data for wetland applications.

Hyperspectral scanners collect large amounts of data, even when imaging a relatively small area at a coarse spatial resolution. For example, if the spatial resolution of a hyperspectral image is 20 by 20 m, and an area of 10,000 by 10,000 m is imaged, the resulting data requires approximately 150 megabytes of disk storage space. The same area imaged with a 2-m effective resolution would yield an image 11 gigabytes in size. Each 20 by 20 m image pixel in the above example would have approximately 220 associated spectral values. The volume of data makes it difficult to extract useful information. Statistical analysis techniques commonly used to process multispectral data are not suited to the amount and dimensionality of data present in a hyperspectral image. The problems encountered in processing hyperspectral data are, in some ways, similar to those experienced in the 1960s with the advent of multispectral data. The volume of data and the CPU-intensive algorithms which were required to extract information from multispectral data presented a challenge to computers of the time. Likewise, the amount of data collected by hyperspectral sensors represents a challenge to today's vastly improved computers.

AVIRIS APPLICATION: To examine the potential future applicability of hyperspectral techniques for monitoring wetlands, an image obtained from the AVIRIS hyperspectral scanner was acquired over an area adjacent to Green Bay, WI. The spectral curves measured over three different wetland types were examined. By viewing the high resolution spectral curves measured by the sensor over similar cover types in concert, it was possible to determine whether or not hyperspectral scanners like AVIRIS offer promise as future tools for routinely monitoring wetlands.

- Study area. The Green Bay West Shores State Wildlife Area is located along the southwest corner of Green Bay. The principal study site was a small coastal wetland area just north of Green Bay, WI (Figure 1). Three different wetland types were selected from 1:24000 scale Wisconsin Wetlands Inventory (WWI) maps. The three wetland types chosen were: Emergent/ wet meadow, narrow-leaved persistent, wet soil (E2K); forested, broad-leaved deciduous, wet soil (T3K); and scrub/shrub, broad-leaved deciduous, wet soil (S3K).

- The AVIRIS scanner: The AVIRIS scanner is an airborne precursor to the High Resolution Imaging Spectrometer (HIRIS), which NASA plans to launch into space as a component of the Earth Observation System (EOS) in the future. The EOS represents a part of NASA's Mission to Planet Earth initiative (Gao et al., 1993, Goetz et al., 1985). AVIRIS was developed to enable the scientific community to conduct investigations into the utility of hyperspectral scanners for applications prior to the launch of the HIRIS. By making AVIRIS data available to scientists in a wide range of fields, it is hoped that the development of data utilization methodologies will be hastened so that hyperspectral data from the spaceborne platform will be employed more effectively. The Jet Propulsion Laboratory (JPL) is responsible for maintaining and operating AVIRIS until the HIRIS is in orbit.

- WRP study. A four step approach was taken to perform an initial investigation into AVIRIS data and to determine if it could be used to delineate different wetlands types. These steps required a basic knowledge of image processing techniques to extract useful information from the data.

  First, the AVIRIS data were loaded from the source tape provided by NASA's Jet Propulsion Laboratory onto a workstation class computer. The imagery acquired over the study area required 145 MB of disk space and was composed of 224 spectral channels, with 16 bit, signed (including negative) values. The image processing software at the WES Environmental Laboratory could display, but not process, 16-bit, signed data. Therefore, it was necessary to rescale the data values into an 8-bit, unsigned range (0-255). The maximum number of channels handled simultaneously by most commercial software packages is 15 to 20. As a result of this limitation, it was necessary to divide the AVIRIS data into separate image files prior to processing.

The second step in processing the imagery was to georeference these data to a common base map (Fig. 1). When aircraft data are collected, the data are not referenced to any coordinate system, or map base; therefore, before an evaluation of the data's usefulness could be conducted, the data had to be referenced to some real world map projection. This allowed overlay vector data from the Wisconsin Wetland Inventory, which had been digitized into a geographic information system (GIS), to be overlayed onto the imagery. Data georeferencing was performed by locating identifiable ground control points which were visible on both the AVIRIS data and 1:24000 scale quad maps, and then resampling the image data using a cubic two-dimensional polynomial algorithm.

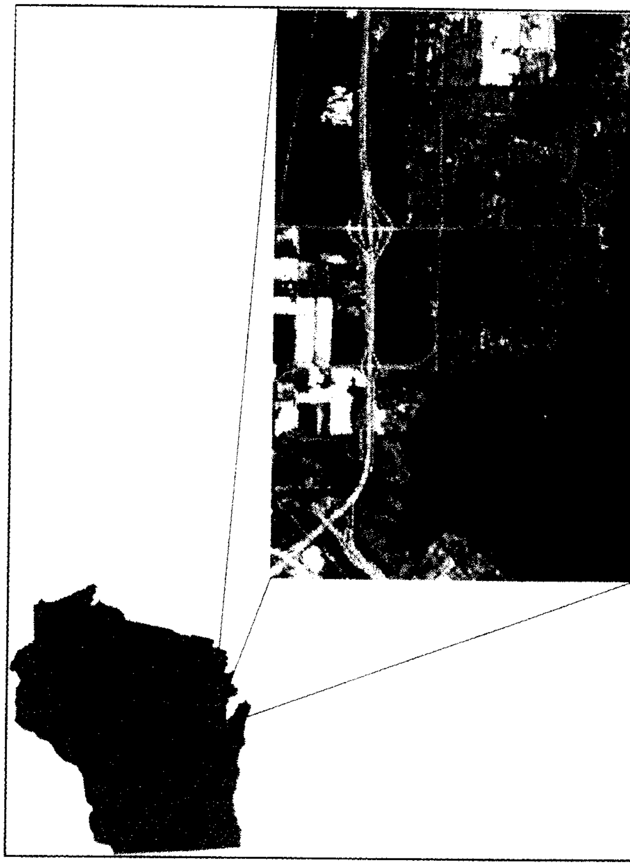

Figure 1. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Data Acquired of the Green Bay, WI Area

The third step consisted of extracting spectral signatures for three different wetland types from the AVIRIS data. The areas of interest were defined by overlaying the Wisconsin Wetland Inventory vector data on the AVIRIS image and extracting homogenous pixels for each of the different polygon types. Four by four pixels blocks were then extracted from within the center of the polygon boundaries to insure that the pixels showed little or no variation in reflectance values and to insure that pixels selected were indeed the correct wetland type. Without taking this precaution, pixels along the polygon boundaries could inadvertently be selected. These boundary pixels could possibly have been indicative of a different wetland type or the result of a "mixed-pixel" effect. The sample extraction areas were then converted to vector format so that data could be extracted from the same areas for each of the 16-channel image files. In the fourth step, image statistics were generated for each of the three wetland types for all 224 channels, resulting in the spectral signatures presented in Figure 2.

- Preliminary results. At first glance, it appears that the three spectral curves presented in Figure 2 are quite similar. In a normal multispectral image, these three cover types would be almost impossible to distinguish, as the small differences which exist in certain portions of the spectrum would be masked by averaging effects. However, with the proper selection of bands (particularly in the near-infrared portion of the spectrum) and the appropriate algorithms, it should be possible to routinely delineate the three cover types of interest using hyperspectral data. These preliminary results indicate that phenological differences between even very similar wetland plant types can be effectively detected with hyperspectral data, but highlight the need for additional research into the use of hyperspectral data for monitoring wetlands.

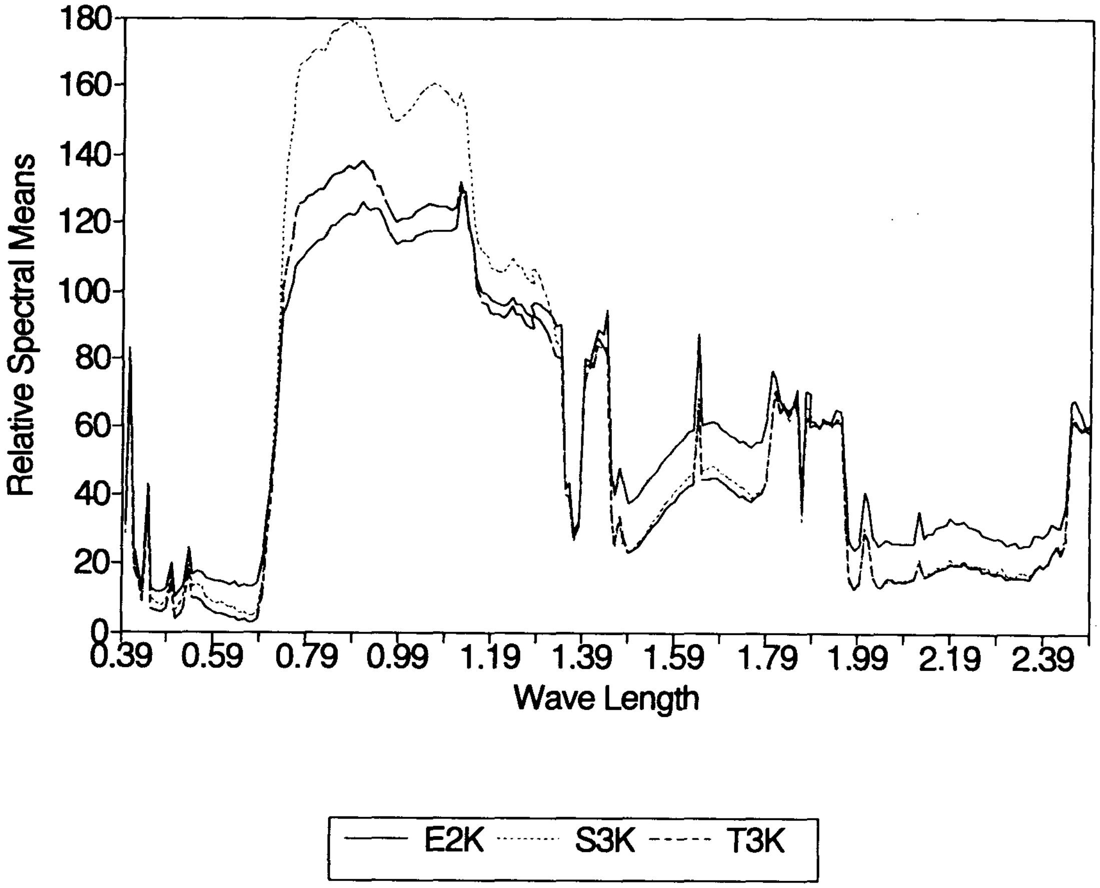

Figure 2. Spectral Means of the Three Wetlands Types

FUTURE DEVELOPMENT: Most of the limitations in using hyperspectral data arise, not from the data itself, but from the current state of the art in processing capability and knowledge of the spectral characteristics of the features of interest. For example, in order to be able to routinely distinguish between similar cover types, it is necessary to have a good understanding of the spectral characteristics of the cover types of interest. The Corps of Engineer's Topographic Engineering Center (TEC), as well as other facilities, are currently conducting "greenhouse" experiments where the spectral signatures of surface cover types are being catalogued in "signature banks." These signature banks will allow researchers to be selective in terms of the channels they select to process out the set of available wavebands. This will reduce the need to process so many channels of data concurrently and limit the size of the image files to be processed. Signature banks could also be used in the future for developing automated techniques for processing hyperspectral imagery. Computers could examine the spectral signatures from all 200 or so spectral channels, compare them to the a huge signature bank, and make accurate decisions as to the composition of the imaged area. This type of analysis is already being conducted in the western United States for geological mapping applications, as the spectral signatures of rocks and minerals are much easier to catalog and are static in nature as opposed to vegetation.

Another limitation of hyperspectral data at this point is the cost of data from hyperspectral platforms. Very few hyperspectral sensors currently exist and data from these sensors are extremely costly. It is also very difficult to schedule overflights from these sensors as they are currently oversubscribed. This limits the usefulness of hyperspectral data at this time; however, with the launch of the HIRIS system, towards the end of this decade, these limitations will no longer apply. It is incumbent on the wetlands research community to encourage further, much more detailed, investigations into the utility of these data for monitoring our wetland resources so that, once data from spaceborne platforms are available, the data may be fully exploited for wetland applications.

FOR MORE INFORMATION CONCERNING THE USE OF HYPERSPECTRAL DATA WITHIN THE CORPS: The Corps of Engineers has establish a Remote Sensing/GIS Support Center to assist in the application of remote sensing technologies. The address is:

U.S. Army Cold Regions Research & Engineering Center
ATTN: Remote Sensing/GIS Support Center (CECRL-RSGISC)/Dr. H. McKim
72 Lyme Road
Hanover, NH 03755-1290
(603)646-4372

Also, the U.S. Army Topographic Engineering Center (TEC), Fort Belvoir, VA, is conducting research on use of Hyperspectral Data and additional information can be obtained by contacting:

U.S. Army Topographic Engineering Center
ATTN: Dr. Jack Rinker
Fort Belvoir, VA 22060-5546

POINTS OF CONTACT FOR ADDITIONAL INFORMATION: Mr. Mark Graves, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-EN-C, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, phone: (601)634-2557.