HYPERSPECTRAL IMAGING

Endless Possibilities from the Power of Datacubes

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A new generation of hyperspectral images is aiding resource management, agriculture, mineral exploration and environmental monitoring applications, to name a few. Hyperspectral sensors differ from multispectral sensors because they measure the intensity of reflected solar energy across a continuous span of wavelengths, recording visible light comprising relatively short blue, green and red wavelengths, as well as longer visible near-infrared (VNIR) and short wave-infrared (SWIR) light.

The airborne hyperspectral sensor collects reflected light as picture elements (pixels). But unlike airborne and satellite multispectral sensors, which use a few detectors that are sensitive to broad wavelength bands of light, hyperspectral sensors subdivide reflected light into ~50 to 200+ discrete and continuous wavelength bands. The large number of spectral bands collected within each pixel or instantaneous field of view (IFOV) is the basis of the name "hyperspectral." Because each pixel has so many bands, a hyperspectral flight strip often is referred to as a "datacube." Sophisticated image-processing packages, such as Research Systems' ENVI software, can display the datacube and color-code the intensity of reflected light from short to long wavelengths along the cube's edge.

Hyperspectral Specifics

The power of hyperspectral remote sensing is most effectively exploited when individual pixels are analyzed for their spectral characteristics. The amount of energy recorded within each pixel—and the spectral signature—varies across the wavelength range collected by the sensor because different materials on Earth's surface reflect or absorb solar energy to varying degrees. Hyperspectral sensors are unique in that they have sufficient spectral resolution to identify different surface materials based solely on spectral signatures (Figure 1).

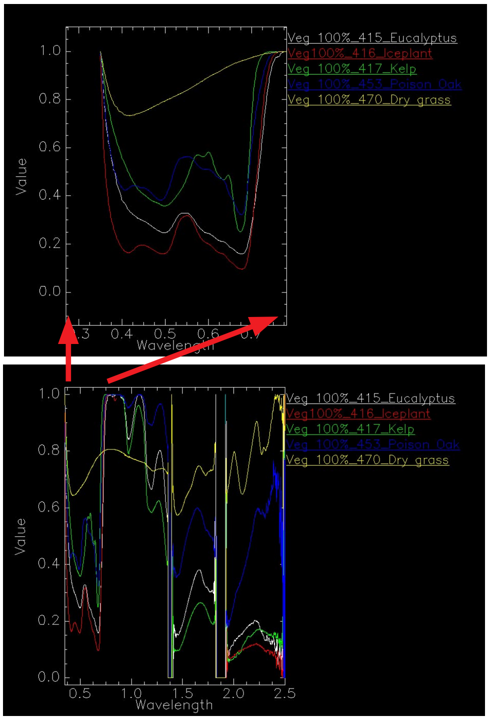
Comparing Sensors

NASA's AVIRIS hyperspectral sensor (*http://aviris.jpl.nasa.gov*) collects 224 continuous bands of light that span from VNIR to SWIR (~.4 to 2.5 micrometers [µm]). Each band averages ~.1 µm wide. Commercial hyperspectral sensors, such as Integrated Spectronics' HyMap (*www.intspec.com*) and Earth Search Sciences' Probe-1 (*www.earthsearch.com*), collect 124 bands of reflected VNIR-SWIR light, with each band averaging ~.15 µm wide.

In contrast to VNIR-SWIR hyperspectral sensors, most multispectral sensors collect four discontinuous (separated) bands of light that cover portions of blue to near-IR (.45 to .90 µm) wavelengths. Each multispectral band is relatively broad, averaging ~.70 µm wide. More and unique spectral information can be extracted from hyperspectral data than from multispectral data because of the fundamental difference in imaging technology.

Spectral Libraries

Because each hyperspectral pixel contains so much unique information, software has been developed that displays the spectral signature of surface materials within a pixel as a profile. A spectral profile shows the intensity of reflection and depth of absorption on the



Earth Search Sciences Probe-1 Imagery from The GeoSAT Committee

More Mesa, Goleta view is east at west end of outcrop
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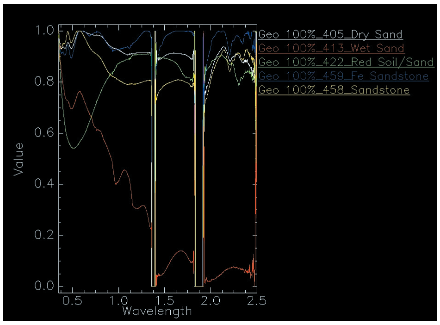

Figure 1: Spectral profiles collected from pixels in an airborne hyperspectral datacube (top center) show unique differences with different vegetation types (left), rocks and soils (right). Other pixels in the datacube with similar composition can be efficiently and accurately classified based on these spectral libraries.

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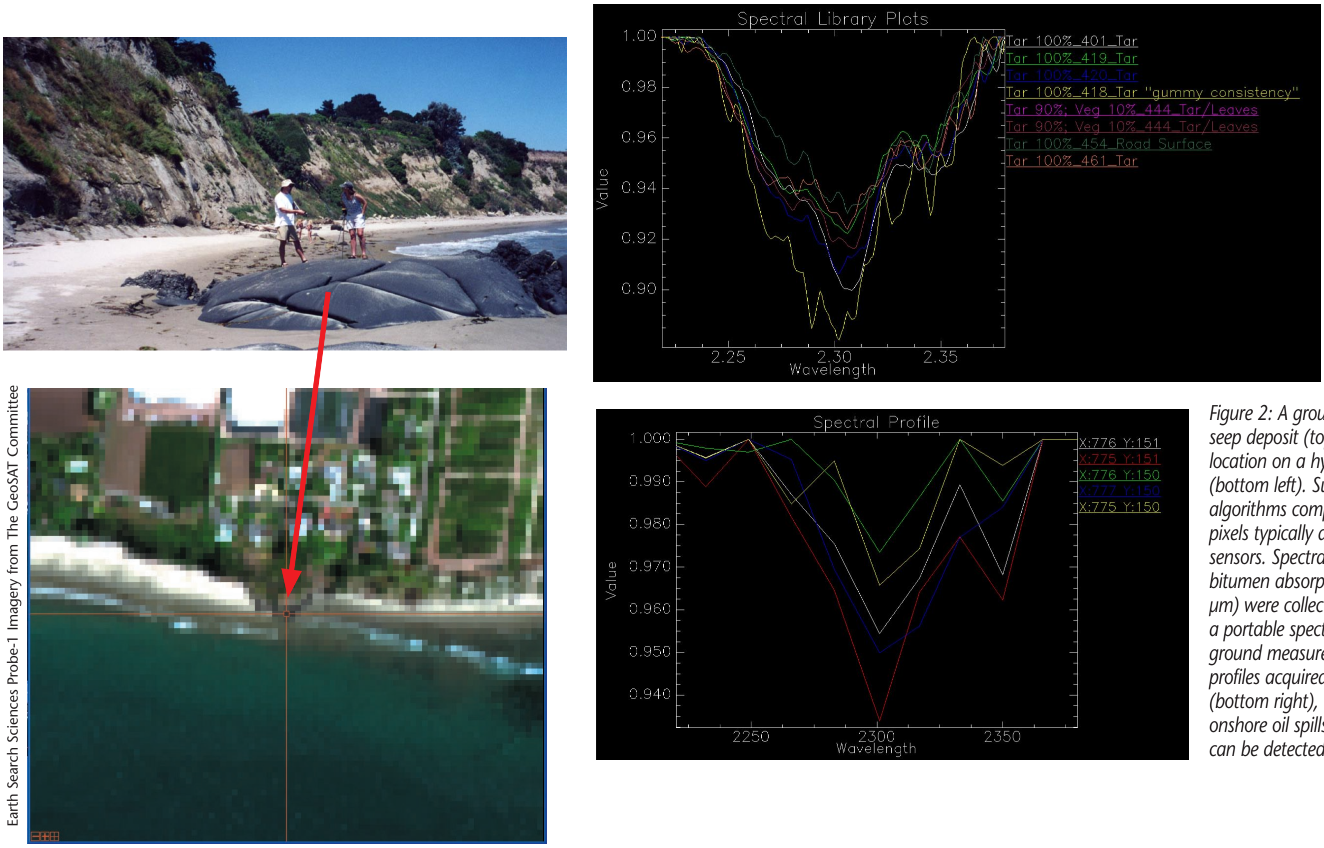
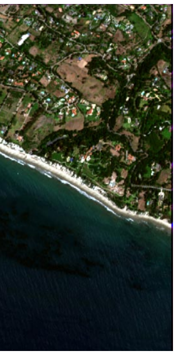


Earth Search Sciences Probe-1 Imagery from The GeoSAT Committee

Figure 2: A ground photograph of an oil seep deposit (top left) verifies the deposit's location on a hyperspectral datacube (bottom left). Subpixel and unmixing algorithms compensate for the larger pixels typically acquired by hyperspectral sensors. Spectral measurements of the bitumen absorption feature (2.2 to 2.4 µm) were collected on the ground with a portable spectrometer (top right). The ground measurements match spectral profiles acquired with an airborne sensor (bottom right), demonstrating that onshore oil spills, seeps and oil-stained soil can be detected from airborne platforms.

vertical axis, and the wavelength range on the horizontal axis. This enables visual correlation of spectral signatures with reference spectra and other pixels in the datacube. The higher the spectral curve, the more reflective the material is to that wavelength of light. The lower the spectral curve, the more absorptive the material is to that wavelength of light. The depth, shape and wavelength location of absorption features in the spectral profile often can identify vegetation imaged within a short time frame, minerals, oil, disturbed soils and man-made materials.



To build a spectral library of different materials, one can collect spectral profiles from "pure" samples of each material in the field or laboratory. Several spectral libraries are available online or are loaded into image-processing software; however, site-specific libraries are more reliable for detailed mapping. Spectral libraries can be used to provide training sites or reference spectra to help derive maps of the surface material from airborne datacubes. As detailed in Figure 2, research has confirmed that airborne sensors collect spectral signatures that closely match those obtained in the field with portable spectroradiometers.

Overcoming Large Pixels

Most pixels contain a mixture of materials—a varying percentage of water, concrete, different plant communities, exposed soil, etc. Hyperspectral data often are collected with larger pixels (3 to 10 meters) than other airborne sensors to maximize the area imaged and reduce acquisition costs. ENVI software contains sophisticated algorithms that compensate for the relatively large pixels. The software allows users to detect targets that cover only a small percentage of the pixel and can spectrally unmix unique surface materials within a pixel to determine their relative abundance. Images can be generated that highlight spectrally unique targets and an abundance of specific materials across an area of interest. These subpixel and unmixing algorithms effectively compensate for the relatively large airborne pixels.

Improving Pixel Location on a Map

Improving horizontal mapping accuracy has been one of the biggest challenges facing the airborne hyperspectral community. Maps derived from hyperspectral datacubes have been exceptional, but getting each pixel into its correct map location for integration with other data in a geographic information system (GIS) has been difficult because of sensor and airborne navigation challenges. Datacubes provided by NASA and most airborne hyperspectral imaging companies now have rectification solutions.

Diverse Applications

Hyperspectral sensors that collect 100+ continuous bands spanning the VNIR-SWIR wavelength range acquire a rich, deep datacube that can be effectively used for many applications. A VNIR-SWIR datacube can be used to evaluate environmental, facility and geologic conditions. VNIR-SWIR hyperspectral sensors are most effective for mapping high-value assets (industrial complexes, brownfields, military installations, wetlands, parks, etc.) and detecting specific targets that have a unique spectral signature. The following sections examine a few of the many applications that benefit from hyperspectral data.

Mapping Geology

Hyperspectral technology is most effective for mapping minerals and rocks. Many minerals have unique and robust spectral absorption features that indicate their composition and identity. Extensive spectral libraries have been published that make hyperspectral mapping of minerals and rocks effective and efficient. The SWIR component is essential for detecting and mapping clays, calcite, anhydrite and other surface minerals.

Spectral characteristics of soils are a function of several properties, including clay mineral composition, texture, moisture, organic matter content, iron-oxide content and surface roughness. These variations in organic and inorganic constituents enable users to identify and accurately map surface soils, especially disturbed soils, with VNIR-SWIR hyperspectral sensors.

Oil Detection

VNIR-SWIR hyperspectral sensors can detect onshore oil spills and oil-stained ground

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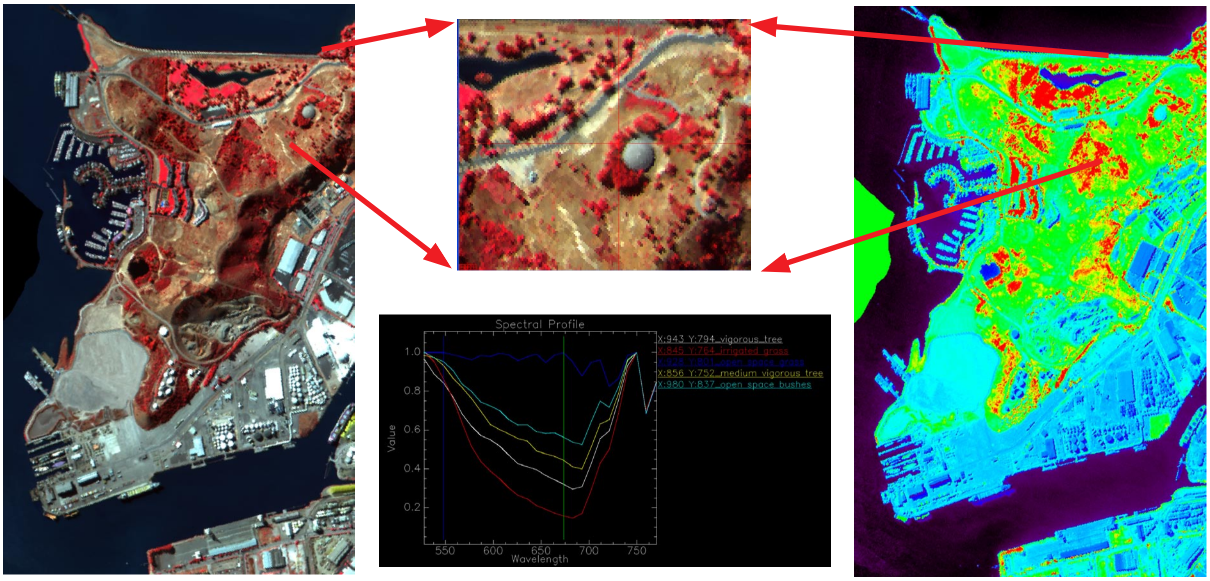

NASA AVIRIS Data

Figure 3: A color-infrared hyperspectral image (left) shows an area with a water tank (top center). A color-coded vegetation vigor or "greenness" map (right) was derived from the image. The most vigorous plants are trees with deep roots and irrigated grass. Compared with the map, spectral profiles (bottom center) of different vegetation types provide much more detailed information on plant vigor/stress. Profiles of different plants show varying chlorophyll absorption features and position and amplitude of chlorophyll red edge (found between ~ .68 to .75 µm). Other pixels in the datacube with similar composition and vigor can be efficiently and accurately classified based on this spectral library.

because oil has unique spectral characteristics (Figure 2). Many analyses have used the bitumen absorption feature at ~2.3 µm as the primary hydrocarbon indicator. Other research has analyzed different absorption features found across the near-IR to SWIR wavelength spectrum. In addition, oil seepage can alter soil surfaces by forming calcite, pyrite, sulfur, iron oxides and sulfides, as well as bleaching red beds, changing clay minerals and prompting chlorophyll red edge shift in affected vegetation. Hyperspectral remote sensing can detect all of these alterations. Oil detection and mapping can be an integral part of an environmental baseline for high-value assets such as oil fields, refineries, tank farms, pipelines and exploration acreage with the use of hyperspectral technology.

Mapping Vegetation

Plant communities and often plant species can be differentiated and mapped with hyperspectral sensors. Plants appear green to human eyes because blue and red light (.45 and .65 µm) are preferentially absorbed while green light (.55 µm) is reflected—this can be seen clearly in spectral profiles of vegetation. Compared with multispectral and film imaging, hyperspectral data quantifies in detail the degree of absorption and reflection in the visible light spectrum by plant pigments in the leaves. Hyperspectral sensors record the high reflectance and transmittance of light with wavelengths of .7 to 1.2 µm—this is related to internal leaf structure and vigor. In addition, the SWIR sensor (~1.4 to 2.5 µm) collects diagnostic information related to plant moisture.

More and unique spectral information can be extracted from hyperspectral data than from multispectral data because of the fundamental difference in imaging technology.

By collecting spectral profiles at pixels (training sites) with known vegetation types, a spectral library can be built that can be used to classify the rest of the vegetated pixels in airborne datacubes. The extrapolation of vegetation spectral libraries to airborne datacubes requires all the data to be collected within a short time frame and under similar environmental conditions. To provide standardized maps of vegetation cover, many narrow-band indices have been developed, including crop chlorophyll content and normalized difference water index.

Vegetation Vigor/Stress

Hyperspectral imaging provides detailed information about vegetation stress across the VNIR-SWIR spectrum. As with multispectral data, informative color-infrared images can be generated using narrow wavelength near-IR, red and green bands. Near-IR and red bands can be used in an NDVI formula to generate a vegetation vigor/stress or "greenness" map (Figure 3).

However, in addition to these images, a visible to near-IR spectral profile of plants in each hyperspectral pixel reveals the shape and depth of the chlorophyll absorption feature. In addition, the position and amplitude of the chlorophyll red edge (found between ~ .68 to .75 µm) can be measured and standard indices developed to map stress or vigor across an area. With the SWIR capability, the level of moisture in plants also can be accurately monitored.

As plants become less vigorous, the depth of the chlorophyll absorption feature decreases and the position of the chlorophyll red edge can shift to shorter wavelengths. This is clearly shown in spectral profiles comparing vigorous to stressed plants. In addition, decreasing water content associated with increasing stress can be seen on spectral profiles across VNIR-SWIR wavelengths, but is most pronounced in the SWIR region. To provide standardized maps of vegetation stress, many narrow-band indices have been published that specify specific wavelengths in the formulas.

Water Quality

To penetrate a clear column of water and map bathymetry, submerged plants and navigation hazards, the remote sensing instrument needs to be able to record reflected blue light (~.4 to .5 µm). Green and red light are scattered in the water column and don't penetrate as deeply as blue light. Longer wavelength near-IR and SWIR light is totally absorbed by clear water—no light is reflected back to the sensor. Clear water is characterized by a relatively flat and decreasing reflectance across the visible to near IR wavelengths.

In contrast, bodies of water that contain varying amounts of organic and inorganic material cause predictable changes in the spectral signatures recorded by hyperspectral sensors. These spectral changes can be correlated with water quality. With increasing concentration, clay- and silt-sized minerals suspended in the water column will systematically alter the spectral signatures within pixels. Microscopic plants and animals suspended in the water column also change water's spectral characteristics. The chlorophyll in microscopic plants (algae) absorbs blue and red light, reflects green light and strongly reflects near-IR light. The more chlorophyll in the water column, the more pronounced the spectral absorption and reflection patterns.

Ever-Expanding Use

Hyperspectral sensors and analyses are providing more information from remotely sensed imagery than ever. As new sensors provide more hyperspectral imagery and new image processing algorithms continue to be developed, hyperspectral imagery is positioned to become a common research, operational and monitoring technology in a variety of fields.

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