Evaluation of Hyperspectral D

Identification of Various Rocks and Minerals

Hyperspectral remote sensing, the measurement of the Earth's surface in up to hundreds of spectral images, provides a unique means of remotely mapping mineralogy. A wide variety of hyperspectral data are now available along with operational methods for quantitatively analyzing the data and producing mineral maps. This paper is meant to illustrate the potential of these data and how it can be used as a tool to aid detailed geologic mapping and exploration.

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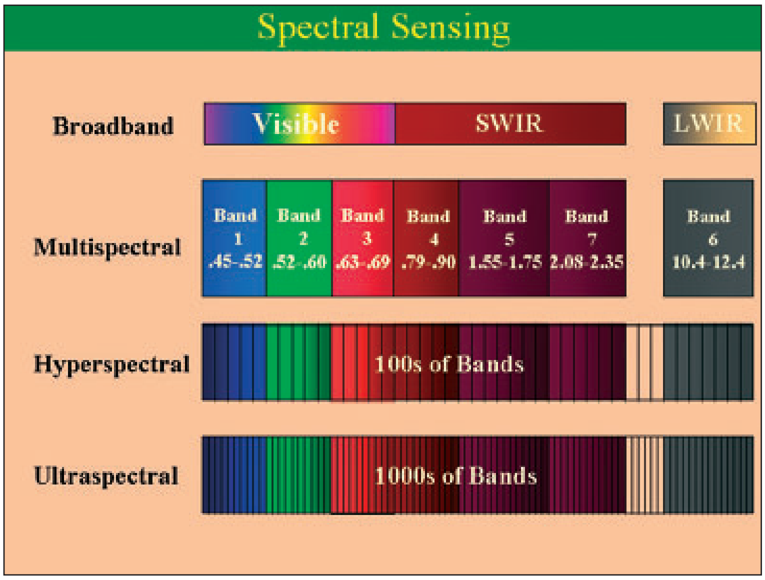

Figure 1: typical hyperspectral frequency bands.

Introduction

Hyperspectral sensors, also known as Imaging Spectrometers, are a systems technology whereby images of a scene are collected in tens to hundreds of contiguous narrow spectral bands nearly simultaneously. They represent the next step in the spectral dimension of the evolution of multispectral (using different parts of spectrum, or using or operating with different parts of the electromagnetic spectrum) imaging radiometers currently represented by satellite sensors such as the Landsat Thematic Mapper which collects data in seven simultaneous bands. The term hyperspectral usually refers to an instrument, whose spectral bands are constrained to the region of solar illumination, that is visible through shortwave infrared and in the remote sensing context has an observing platform that is either airborne or spaceborne. The data collected are often termed as an 'image cube' where the two spatial dimensions are joined by the third spectral dimension. All objects reflect, absorb, or emit electromagnetic radiation based on their composition.

A hyperspectral sensor, using reflected solar radiation (0.4 µm- 2.5 µm wavelength range), captures the unique spectra, or 'spectral signature', of an object, which can then be used to identify and quantify the material of which it is composed. The electromagnetic spectrum covered by a range of hyperspectral imagers is shown in Figure 1.

Spectral Signatures

The recent developments in hyperspectral sensors have opened new vistas for the monitoring of the Earth's surface by using remote sensing images. In particular, hyperspectral sensors provide a dense sampling of spectral signatures of land covers, thus allowing a better discrimination among similar ground cover classes than traditional multispectral scanners (Lee et. al., 1993). However, at present, a major limitation on the use of hyperspectral images lies in the lack of reliable and effective techniques for processing the large amount of data involved.

In this context, an important issue concerns the selection of the most informative spectral channels to be used for the classification of hyperspectral images. As hyperspectral sensors acquire images in very narrow spectral bands, the resulting high-dimensional feature sets contain redundant information. Consequently, the number of features given as input to a classifier can be reduced without a considerable loss of information (Fukunaga, 1990). Such reduction obviously leads to a sharp decrease in the processing time required by the classification process. The field of spectroscopy is concerned with the measurement, analysis, and interpretation of mineral spectra. Combining spectroscopy with methods to acquire spectral information over large areas is known as imaging spectroscopy. The principles involved in the application of imaging spectroscopy to perform satellite remote sensing are illustrated in Figure 2. Hyperspectral sensors are a class of imaging spectroscopy sensors in which the waveband of interest is divided into hundreds of contiguous narrow bands for the purpose of signature analysis.

Spatial Sampling Resolution

There are four sampling operations involved in the collection of hyperspectral data: spatial, spectral, radiometric, and temporal. The spatial sampling resolution, or ground pixel size, varies from a few meters to tens of meters and is a function of the sensor aperture and platform altitude that, in turn, depends upon the kind of platform, space- or airborne. The spectral sampling can be accomplished by a variety of means such as a prism or interferometer. A/D converter

ata for Geological Mapping

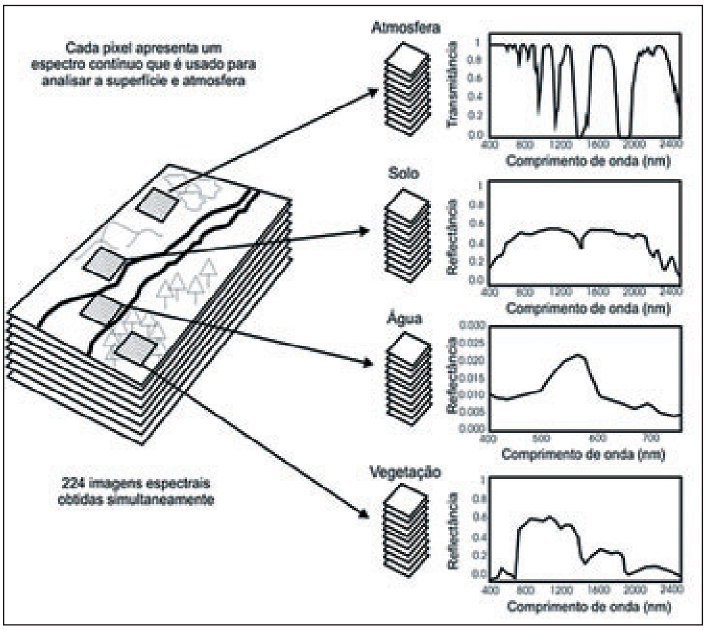

Figure 2: Schematic illustration of the imaging spectrometry concept. Images are acquired simultaneously of up to several hundreds of narrow spectral bands providing a complete reflectance spectrum for every pixel in the imaging spectrometer scene. (Courtesy: www.sed.manchester.ac.uk/.../uperu/project4.htm)

samples the radiance measured in each spectral channel producing the digital data, at the prescribed radiometric resolution, that comprises a hyperspectral cube. Temporal sampling corresponds to the collection of multiple hyperspectral images of the same scene over time and is an important mechanism for studying environmental changes. Typically, the analysis of a hyperspectral scene involves the decomposition of each pixel in the image into its constituents. These are represented by spectra of relatively pure material, which are themselves extracted from the scene. The identity of these constituents is determined by comparison with 'library' spectra of known materials measured in the field or in the laboratory. Hyperspectral data will enable the identification of terrestrial features with greater accuracy and the capability of developing unique image products which are not possible by using the current generation of spaceborne sensors. A spaceborne hyperspectral sensor will be an enabling tool used to monitor both static and dynamic targets at high spectral and spatial resolution.

Exploration Geology

Because of the unique spectral characteristics of many alteration and rock-forming minerals, hyperspectral remote sensing can make a significant contribution to the field of mapping and exploration geology. Remote sensing imagery has become an important tool to worldwide geologic and mineral mapping. With economic and exploration frontiers expanding globally, the use of multispectral and hyperspectral systems plays a significant role in mapping and evaluating developing countries, overseeing reconstruction efforts in foreign lands, and monitoring international mining and environmental conditions. Airborne and spaceborne sensors provide a valuable digital imagery that allows lithologic (rocks: their origin and formation and mineral composition and classification) and stratigraphic identification (the identification of strata, or layers), geomorphic and structural interpretation, rock alteration and mineral prediction, as well as geobotanical observations, all on a worldwide scale. All geological maps contain an image that describes the spatial distribution of the lithologies (folds and faults), and a stratigraphic column that describes the temporal relationships of lithologies.

Challenges

Geological mapping comprises a number of challenges. First, the identification of lithologic contacts and their differentiation by spectral signatures are complicated by mechanical breakdown of the lithologies into boulder fields, which do not provide a homogeneous target for remote sensing. Different approaches to image segmentation include spectral signature based Minimum Noise Fraction (MNF) transformation and edge detection algorithms. Second, hyperspectral imagery records the spectral signature of weathered surfaces of the various lithologies. Identification of a specific lithotype is rarely defined by reference to library spectra but more commonly to field acquired characteristic spectra. Third, establishing the stratigraphic and structural relationships of rock units requires some knowledge of their three-dimensional distribution.

Magmatic Rocks

Pluralities of remote sensing applications have shown that hyperspectral reflectance data can be used for identification of various rocks and minerals, due to their unique spectral characteristics such as absorption features. However, identification with respect to the mineralogical composition of magmatic rocks can not be achieved by using this wave length range. These rocks possess their specific spectral features as emission minima mineralogical composition. The most intensive spectral features of the siliceous rock forming minerals can be observed between 8μm and 14μm due to fundamental vibration of atoms and molecules. For rock identification using rock spectra, knowledge about spectral behavior and spectral variations of the constituents is needed. This is because a rock spectrum can be described by the combination of the particular spectra of the rock forming minerals.

Mineral Exploration

Mineral exploration is becoming increasingly difficult. Especially in ground access sensitive or remote geophysical methods can be used to provide the detailed physicochemistry (mineralogy, chemistry and morphology) of the Earth's surface. This information is useful for mapping potential host rocks, alteration assemblages and regolith characteristics. In contrast to the older generation of low spectral resolution systems, such as the

Figure 3: Aster Image with SWIR bands 4-6-8 in RGB, and highlights lithologic and alteration differences of surface units. (Courtesy: http://asterweb.jpl.nasa.gov/gallery-detail.asp?name=Escondida)

Landsat Thematic Mapper (TM) with only six 'reflected' bands, the new generation of hyperspectral systems enables the identification and mapping of detailed surface mineralogy using 'laboratory-grade' spectroscopic principals (Clark et. al., 1990).

Absorption Features

Investigations carried out over the last 15 years show that hyperspectral remote sensing can make major new contributions to the advancement of geological applications, especially in the areas of identification and mapping of minerals, and lithological mapping in arid and semi-arid environments. This is possible since hyperspectral sensors, in contrast to other existing broad-band multi-spectral sensor systems, are able to resolve absorption features unique to specific minerals.

For example in Figure 3 the ASTER image covers 30 by 37 km in the Atacama Desert, Chile and was acquired on April 23, 2000. The Escondida Cu-Au-Ag open-pit mine is at an elevation of 3050 m, and came on stream in 1990. Current capacity is 127,000 tons/day of ore; in 1999 production totaled 827,000 tons of copper, 150,000 ounces of gold and 3.53 million ounces of silver. Primary concentration of the ore is done on-site; the concentrate is then sent to the coast for further processing through a 170 km long network consisting of 9 pipes. Escondida is related geologically to three porphyry bodies intruded along the Chilean West Fissure Fault System. A high grade supergene cap overlies primary sulfide ore. The image displays SWIR bands 4-6-8 in RGB, and highlights lithologic and alteration differences of surface units.

Hyperspectral data provide a means of identifying the surface mineralogy, and are an aid to lithological mapping. Hyperspectral is not a variant of multispectral such as Landsat, SPOT, IRS and alike information that fills map drawers and hard disks. However it has been of question when it comes to finding ore. Many common minerals can be identified using hyperspectral sensors. The value of the hyperspectral imaging from an explorationist's point of view is based on practical experience with the technology.

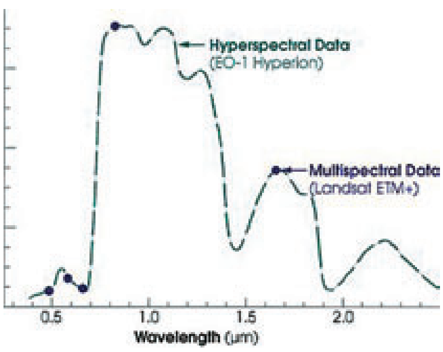

Figure 4: Spectral resolution of multispectral and hyperspectral systems.
(Courtesy: http://earthobservatory.nasa.gov/Library/EO1/ eo1_2.html).

Hyperspectral is not multispectral and here is why: multispectral simply does not have the spectral resolution to identify minerals.

Spectra

Spectral resolution is important for detecting fine spectral features that can be identified specific materials. Figure 4 shows Hyperion1, the hyperspectral imager on EO-1, which will measure much finer spectral information than the ETM+ (Landsat 7 Enhanced Thematic Mapper Plus) or ALI (Advanced Land Imager). In nature, spectral information is continuous—the amount of sunlight reflected off a point on the Earth's surface varies smoothly with changes in wavelength. Hyperion's 220 bands (green line) provide a more accurate depiction than the discrete bands of Landsat (blue dots).

Applications

The following sections outline the mineral exploration applications that will benefit from the availability of spaceborne hyperspectral remote sensing data. For each application area, hyperspectral products are identified, and potential benefits of hyperspectral data are outlined.

Two major application areas of hyperspectral data to mineral exploration have been identified:

- Lithologic mapping, or direct sensing of bedrock and minerals;
- Geobotanical mapping or indirect sensing of surficial geology.

The use of hyperspectral data for geobotanical mapping is far less mature than lithologic mapping, but nevertheless represents a large potential market.

The key goals in mineral exploration are: 1) to gain a preliminary understanding of a geographic area through lithological mapping and 2) to assist in defining potential exploration targets prior to initiating intensive field exploration activities. Spaceborne hyperspectral data are well-suited to mapping bedrock and identifying the presence and abundance of specific diagnostic minerals at specific scales.

Hyperspectral Products

Products derived from hyperspectral data include categorized images of bedrock distribution with geological labels, and maps detailing the distribution of specific minerals and their abundances. These maps provide geologists with an additional tool to decipher the overall lithologic and structural history of a region, and help to define potential exploration targets.

The minerals which have been successfully

identified to date with imaging spectroscopy can be grouped as follows: OH-bearing minerals, carbonates, sulfates, olivines, pyroxenes, iron oxides and hydroxides. The identification of minerals and the mapping of their distribution provide the necessary underpinnings for exploration purposes (such as precious and base metals, and diamonds), and lithological (rock) mapping. The latter application is of particular interest in areas where either no maps or much generalized maps exist, such as in arctic environments. The first category also includes petroleum exploration where hyperspectral remote sensing may assist in the detection of hydrocarbon micro-seepage.
To be useful to the end users, products derived from spaceborne hyperspectral data should be readily integratable with other data sources, possibly in a geology-specific GIS. The analysis of the products is typically conducted in conjunction with traditional geophysical data (magnetics, gamma-ray). Availability of digital elevation data (DEM) at a scale of 1:20,000 is also beneficial in the analysis of hyperspectral data.

Benefits

The prime benefit of hyperspectral remote sensing to the user community is the ability to identify the presence and abundances of specific diagnostic minerals that will help direct mineral exploration activities to areas of high potential at considerable cost savings. Hyperspectral sensors, for example the AVIRIS (Airborne Visible/Infrared Imaging Spectrometer), collects data that can be used for characterization of the Earth's surface and atmosphere from geometrically coherent spectroradiometric measurements. This data can be applied to studies in the fields of oceanography, environmental science, snow hydrology, geology, volcanology, soil and land management, atmospheric and aerosol studies, agriculture, and limnology. Applications under development include the assessment and monitoring of environmental hazards such as toxic waste, oil spills, and land/air/water pollution. With proper calibration and correction for atmospheric effects, the measurements can be converted to ground reflectance data which can then be used for quantitative characterization of surface features. In Figure 5 the image is an example of research conducted by the United States Geological Survey using AVIRIS data. The image is a Fe (Iron)-bearing mineral map (0.35 to 1.35 micron spectral region) in the Antelope Range (AVIRIS flight 980805t01p02_r10) derived from Tetracorder analysis of AVIRIS data.

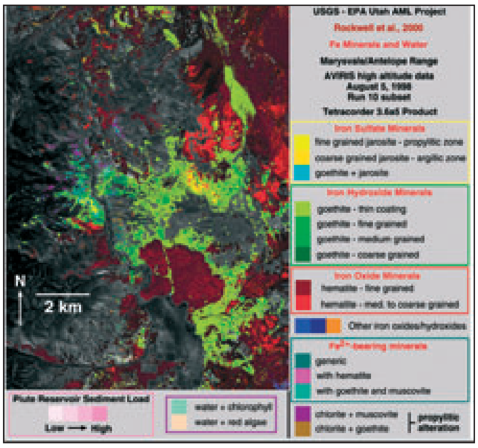

Figure 5: AVIRIS image is a Fe (Iron)-bearing mineral map (0.35 to 1.35 micron spectral region). (Courtesy: http://aviris.jpl.nasa.gov/html/data.html)

Geobotanical Mapping

In most areas of the world, surface geology is to some degree obscured by vegetation. Geobotanical mapping, or exploration in vegetated environments, has the potential of identifying the areal distribution of specific element-associated spectral changes in vegetation which are related to soil geochemistry, lithology, or surficial materials. This approach makes use of the fact that the reflection of vegetation is spectrally affected in the presence of heavy metals or alteration zones. For example, accumulation of heavy metals induces stress on the vegetation causing a shift of the red-edge (680-800nm). Such a shift is only detectable with a hyperspectral imager.

Hyperspectral Products

The idea is that spaceborne hyperspectral data allows identification of element-specific geobotanical anomalies on the basis of absorption features or changes in the continuum of vegetation spectra. The output products would consist of classified images or maps of the areal extent (and degree) of element-specific geobotanical variations. Geobotanical anomalies associated with ore bodies may also be expressed as abrupt changes from one plant community to another as a function of the underlying surficial geology and not necessarily due to stress induced physiological changes in plants. Although the use of geobotanical mapping is very promising, the ability of achieving element specific geobotanical products is not yet well developed and requires further basic research and development before it achieves operational status.

Benefits

Currently spaceborne multi-spectral sensors are capable of providing gross lithologic information or identification of stressed vegetation, but not detailed mineralogy or geobotany of importance for mineral exploration. This function is currently undertaken by field crews, which is expensive and time-consuming. Hyperspectral remote sensing can potentially have a significant impact in detecting geobotanical anomalies or trends.

Summary

Pluralities of remote sensing applications have shown that hyperspectral reflectance data can be used for identification of various rocks and minerals. Because of the unique spectral characteristics of many alteration and rock-forming minerals, hyperspectral remote sensing can make a significant contribution to the field of exploration geology. The high spectral resolution characteristic of hyperspectral sensors preserves important aspects of the spectrum, for example the shape of narrow absorption bands, and makes differentiation of different materials in the ground possible. The data in each band corresponds to a narrowband image of the surface covered by the field of view of the sensor, whereas along the wavelength dimension, each image pixel provides a spectrum characterizing the materials within the pixel.

Hyperion1: It is an instrument which provides a high resolution hyperspectral imager capable of resolving 220 spectral bands (from 0.4 to 2.5 µm) with a 30 meter spatial resolution. The instrument images a 7.5 km by 100 km land area per image and provides detailed spectral mapping across all 220 channels with high radiometric accuracy.

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