Chapter 15

REMOTE SENSING TECHNIQUES

Introduction

This chapter briefly summarizes the capabilities, limitations, and requirements of typical remote sensing techniques. Depending on the nature of the data and the objective of the study, geologic interpretation of remotely sensed data may be simple or complicated. Remote sensing is a tool that makes some tasks easier, makes possible some tasks that would otherwise be impossible, but is inappropriate for some tasks. Depending on the individual situation, remote sensing may be extremely valuable. Some remote sensing interpretations can stand on their own with confidence, but for most, establishing ground truth is essential.

Imaging Systems

There are three main types of imaging systems, two of which are widely used in terrestrial applications:

Photographic.—Cameras and film are used. Photography provides the best spatial resolution but less flexibility in spectral data collection and image enhancement. Spatial resolution is dependent on altitude, focal length of lenses, and the types of film used. Spectral resolution is limited to visible and near infrared wavelengths.

Electronic Spectral Sensors.— Detectors are used, usually scanners, that may have less spatial resolution than photographs but can gather spectral data over wide spectral ranges that enable a wide variety of imaging processing, mineral, and geologic identification. These remote sensing systems include satellites, such as Landsat, airborne sensors carried on aircraft, and spectrometers carried on the ground. This type of remote sensing has several categories, including multispectral, hyperspectral, and imaging spectroscopy.

Vidicon. – A television-type system. Vidicon systems generally are inferior to other types both spatially and spectrally. They are used mostly on space probes because of operational constraints.

Resolution

Two types of resolution are important to remote sensing.

Spatial.— The sharpness of an image and the minimum size of objects that can be distinguished in the image are a function of spatial resolution.

Spectral.—The width or wavelength range of the part of the electromagnetic spectrum the sensor or film can record and the number of channels a sensor uses defines spectral resolution. The electromagnetic spectrum is an ordered array of electromagnetic radiation based on wavelength. Certain portions of the electromagnetic spectrum, including the visible, reflective infrared, thermal infrared, and microwave bands, are useful for remote sensing applications. Rocks, minerals, vegetation, and manmade materials have identifying spectral signatures and distinctive absorptive and reflective spectral characteristics. Given sufficient spectral data, digital image processing can generally identify unique spectral signatures. In practice, instrument limitations or cost limits on computer processing may preclude identification of some materials.

Photography

The uses of aerial photography in engineering geology are discussed in Volume 1, chapter 6. A brief description of types is presented below.

Panchromatic photography records images essentially across the entire visible spectrum and, with proper film and filters, also can record into the near-infrared spectrum. In aerial photography, blue generally is filtered out to reduce the effects of atmospheric haze.

Natural color images are recorded in the natural colors seen by the human eye in the visible portion of the spectrum.

False-color infrared images are recorded using part of the visible spectrum and part of the near-infrared, but the colors in the resultant photographs are arbitrary and not natural. Infrared film commonly is used and is less affected by haze than other types.

Multispectral photographs acquired by multiple cameras simultaneously recording different portions of the spectrum can facilitate interpretation.

Terrestrial photographs acquired on the ground or at low altitude with photogrammetric cameras can be used to map geologic features such as strike and dip of joints, faults, and geologic contacts. This type of geologic photogrammetry can also be done from historic construction photographs if enough survey control features can be located in the photographs and tied to present control or known points. Terrestrial photogrammetry has proven useful on several dam projects in which mapping of geologic features by standard methods was very difficult or impossible.

Thermal Infrared Imagery

Thermal infrared systems create images by scanning and recording radiant temperatures of surfaces. Some characteristics of thermal image data are generic to digital image data, and enable computer image processing. Other characteristics are unique to thermal infrared images and make thermal image data valuable interpretive tools.

Thermal infrared imagery can be interpreted using conventional photogeologic techniques in conjunction with the thermal properties of materials, instruments, and environmental factors that affect the data. Where thermal characteristics of a material are unique, thermal infrared imagery can be easy to interpret and can be a great help in geologic studies. Thermal characteristics of a material can vary with moisture content, differential solar heating, and topography making interpretation more difficult and ambiguous.

Multispectral Scanner Imagery

Multispectral scanner (MSS) images are a series of images of the same target acquired simultaneously in different parts of the electromagnetic spectrum. MSS images are an array of lines of sequentially scanned digital data. They may have unique distortions and may or may not have high resolution or information content. Scanner systems consist of scanning mechanisms, spectral separators, detectors, and data recorders.

A digital image is actually an array of numerical data and can be computer processed for a variety of purposes. Geometric distortions caused by sensor characteristics can be removed or distortions can be introduced.

Computer processing can be used to precisely register a digital image to a map or another image. Various types of data (e.g., thermal and visible imagery or a digital image and digitized gravity data) can be merged into a single image. Subtle information, difficult to interpret or even to detect, can sometimes be extracted from an image by digital processing.

Airborne Imaging Spectroscopy

The "image," or data, consist of an array of reflected spectra collected in a two-dimensional array of pixels. Specific spectral features may be identified and pixels with the same spectral wavelength feature may be mapped in colors. Different colors are assigned to different reflectance spectra, and an image is generated from these classifications. A number of different airborne systems are becoming available with various spatial and spectral characteristics. A few commercially available systems are capable of recording 10 or more spectral bands simultaneously, ranging from ultraviolet to thermal infrared wavelengths. The key factor in spectral identification of materials, geologic features, or vegetation is the system's spectral resolution or number of channels. Currently, the premier sensor for imaging spectroscopy is the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory airborne visible and infrared imaging spectrometer (AVIRIS). AVIRIS simultaneously collects data over a spectral range of 0.4 micron to 2.4 microns in 224 channels. The number of channels and very high quality of data allow discrimination of very small spectral absorption features and, therefore, the user can distinguish and map hundreds of types of minerals or vegetation. The AVIRIS instrument is operated by Jet Propulsion Laboratory (JPL) onboard a NASA ER-2 (modified U-2). Commonly operating at an altitude of 63,000 feet, the spatial resolution is approximately 20 meters. The AVIRIS instrument is also operated by JPL onboard a twin-engine aircraft at lower altitudes. The spatial resolution is approximately 1 meter. The size of data sets and the number of separate spectral bands on some airborne systems may require data consolidation or careful selection of data subsets for special processing. Because the Earth's atmosphere introduces it's own spectral absorption features along the light path from the ground to the sensor, removal of atmospheric spectral features is essential to proper analysis of spectroscopy or hyperspectral data. Ground calibration spectra using a field spectrometer operating over the same wavelength ranges and resolution collected at the same time as the overflight is generally required to achieve the highest quality mapping and discrimination of materials. Interpretation usually involves normal photogeologic techniques along with knowledge of spectral characteristics and the data manipulations applied. The spectral imaging data can be analyzed with specialized commercially available software, which relies primarily on statistical analyses and projection of a few spectral features in an image. Software being developed at the U.S. Geological Survey (USGS) Imaging Spectroscopy Laboratory is based on a comparison of laboratory spectral features of several hundred minerals and materials in a spectral library. This software, known as "Tetracorder," rapidly identifies and maps all the key spectral features of known minerals or materials in each pixel of an AVIRIS or other hyperspectral image. The companion field spectrometer can also be used in its own right to collect both laboratory and field spectra of materials for identification. Applications may include distinguishing different types of clay minerals (e.g., expansive or not) as the geologist maps in the field in real time.

High resolution can be obtained and, with proper band selection and processing, complex geochemistry, mineralogy, vegetation, or other materials information can be mapped from the imagery. These technologies have been used very successfully in mapping large areas for several environmental/engineering geology related projects. Because of the complexity of the geology and the size of the area studied, the calibration and analysis of imaging spectroscopy data is not trivial. The volume of high quality data that can be collected using imaging spectroscopy over immense areas in one flight may provide an advantage over any other traditional method of mapping in certain applications.

Satellite Multispectral Scanner Imagery

Landsat is the NASA satellite for civilian remote sensing of the Earth's land surface. The Landsat MSS records seven bands at 30-meter resolution. The MSS is useful for some geological applications, although it is oriented primarily toward agricultural uses. The Landsat 7 is equipped also with a thematic mapper (TM) that has increased spatial and spectral resolution compared to the MSS.

SPOT, a French satellite, provides panchromatic imagery with up to 10-meter spatial resolution. MSS imagery is capable at 20-meter resolution of stereo imaging. Other commercially available satellites designed for rapid and repeated imagery of customer-selected sites are also being put in orbit to produce imagery of any area. In addition, archives of once classified satellite imagery gathered by United States spy satellites have become available to the public and government agencies and may be a source of data and images.

Satellite imagery provides a synoptic view of a large area that is most valuable for regional studies. With increasing resolution and new sensors, site-specific geologic mapping with satellite images is also of value to engineering geology.

Radar Imagery

Radar is an active remote sensing method (as opposed to passive methods like photography and thermal infrared) and is independent of lighting conditions and cloudiness. Some satellite radar imagery is available, like Landsat, and coverage may be useful for regional geologic studies. Side-looking airborne radar (SLAR) produces a radar image of the terrain on one side of the airplane equivalent to low-oblique aerial photography. Radar interferometry is a quickly emerging field of radar remote sensing. Radar interferometry techniques will detect very small changes in topography, such as those caused by landslide movements, fault displacements, erosion, or accretion, and can be mapped remotely over large areas.

Radar imagery has some unusual distortions that require care in interpretation. Resolution is affected by several factors, and the reflectivity of target materials must be considered. The analysis and interpretation of radar imagery requires knowledge of the imaging system, the look direction, and the responses of the target materials.

Radar can penetrate clouds and darkness and, to some extent, vegetation or even soil. Distortions, image geometry, and resolution can complicate interpretation, as can a lack of multispectral information.

Side Scan Sonar

Side Scan Sonar (SSS) is used for underwater surveys and not remote sensing in the typical sense of using aerial or space platforms to image the Earth's surface. SSS produces images underwater and may have useful applications to engineering geologic studies of reservoirs, dams, and other structures or surfaces hidden by water. SSS works by sending out acoustic energy and sensing the return of the acoustic signal. Materials on the bottom surface under water reflect the signal at different strengths depending on the material properties and the angles of incidence and reflection of the signal. The varying strength of signal return is then used to form an image. An image of the reflected signal that looks like a black and white aerial photograph is the output. The acoustic signal is generated by a torpedo-like instrument that is towed behind a boat by cable. Resolution of objects or features on the bottom of a reservoir varies with the frequency of the signal generated and the height of the torpedo above the bottom of the water body.

Single- and Multi-Beam Sonar

Other types of sonar devices that can be used to map the topographic surface of a reservoir bottom include single-beam and multi-beam sonar. These devices send a direct acoustic signal and measure the time of return. This is translated to a depth to the bottom or feature. By sending continuous signals along a line of survey, a profile of the bottom is developed. When multiple lines are tied together in criss-crossing patterns with Global Positioning System (GPS) positions being recorded simultaneously, a topographic map of the bottom can be generated. Multi-beam systems send out multiple beams at different angles simultaneously, thereby generating a topographic surface over much larger areas in greater detail than single-beam systems.

Applications to Engineering Geology

The most useful form of remote sensing for engineering geology applications is aerial photography because of its high resolution, high information content, and low cost. Various scales of aerial photography are available for regional and site studies, for both detecting and mapping a wide variety of geologic features.

Applications of other forms of remote sensing to engineering geology depend on the nature of the problem to be solved and the characteristics of the site geology. Some problems can best be solved using remote sensing; for others, remote sensing is of little value. In some cases, the only way to find out if remote sensing can do the job is to try it.

Appropriate remote sensing data are often not available for the area of interest, and the data must be acquired specifically for the project. Mission planning and time and cost estimating are critical to a remote sensing data collection program. Numerous factors make planning a remote sensing mission more complicated than planning a conventional aerial photographic mission. Remote sensing mission planning is best done in consultation with someone with experience in the field.

Estimating the cost of data acquisition is relatively easy. Estimating the cost of interpretation is a function of the time and image processing required and is much harder. Some forms of remote sensing are inexpensive to acquire and require little processing to be useful. Other forms may be expensive to acquire or may require much processing, perhaps needing experimentation to determine what will work in an untried situation. The cost must be weighed against the benefits.

Bibliography

Two excellent reference books on remote sensing and applications to geology are:

Sabins, F.F., *Remote Sensing Principles and Interpretation,* 2nd edition: Freeman, New York, 449 p., 1987.

Siegal, B.S., and Gillespie, A. R., editors, *Remote Sensing in Geology,* Wiley & Sons, New York, 702 p., 1980.

For a thorough treatment of remote sensing ("more than you ever wanted to know about remote sensing"), including a 287-page chapter on geological applications with abundant color images, see:

Colwell, R N., editor, *Manual of Remote Sensing,* 2nd edition, Falls Church, Virginia, American Society of Photogrammetry, 2724 p., 1983.