Airborne Hyperspectral and Ground-Truth Technologies

INTRODUCTION TO SPECTRAL IMAGING

The human eye is limited to processing imagery as a function of red, green and blue (RGB). Multispectral and hyperspectral imaging techniques take the electromagnetic spectrum and break it into many bands. Hyperspectral imaging captures hundreds of narrow bands over a continuous spectral range to produce the spectra of all pixels in the scene. By comparison, multispectral deals with far fewer bands (three to 10) and can have gaps between them. Hyperspectral is thus seen as a preferred imaging technique aboard earth-orbiting commercial satellites, fixed-wing aircraft, and small and light UAVs because it can collect vast quantities of data.
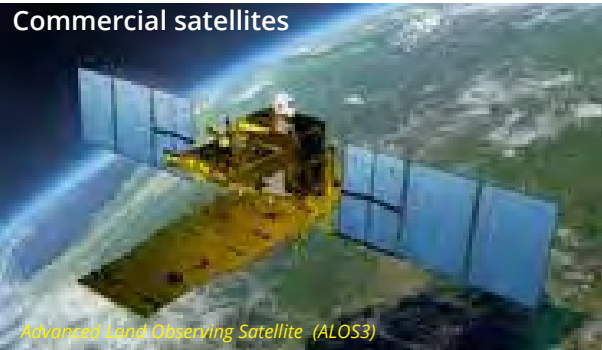
Sensors and imagers generally evolved from military/reconnaissance applications requiring large, elaborate, and costly solutions. But commercialization of this technology (COTS) is allowing airborne hyperspectral technology to reach across a broad spectrum of application areas. Headwall Photonics is producing sensors packed with technical advantages that field scientists need: high SNR, high spatial and spectral resolution, and a very wide field-of-view.

REMOTE SENSING

Broadly, remote sensing is defined as interpreting information about an area or object without being in direct physical contact with it. For earth observation, airborne remote sensing provides us with a wealth of useful information unobtainable solely from ground-based platforms. Sensors are critical to environmental and land research, touching everything from agriculture to pollution control. Capturing the field of view with exceptional precision is the objective of any spectral sensor.

Remote sensors fall into two general categories: active and passive. Both involve the measurement of reflected or emitted energy across specific portions of the electromagnetic spectrum. This spectrum defines the continuous range of electromagnetic radiation from high-frequency/short wavelength gamma rays to low-frequency/long wavelength radio waves. Major discrete regions of the electromagnetic spectrum include gamma rays, x-rays, ultraviolet, visible light, infrared, microwaves, and radio waves.

USE HYPERSPECTRAL ANYWHERE!

Commercial satellites

Advanced Land Observing Satellite (ALOS3)

Fixed-wing aircraft

NASA Goddard Space Flight Center

UAS

Nano-Hyperspec on Aibotix X6

Active sensors produce their own source of energy that is projected, reflected, and detected. Most active sensors operate in the microwave portion of the electromagnetic spectrum and can penetrate the atmosphere and detect surface variations under any solar or atmospheric conditions.

Passive sensors utilize naturally occurring solar radiation or thermal energy to produce measurable electromagnetic wavelengths that are reflected, transmitted, absorbed or emitted by the target's surface. Passive measurements can be detected by spectrometers, which measure the distribution of reflected radiation intensity at specific wavelengths of a known material, or by imaging spectrometers, which measure the spectral distribution of reflected radiation at each pixel in an image of a scene.

With the underlying molecular structure of an object dictating the distribution of its reflectance and absorption features, the resulting spectral signature serves as a unique fingerprint in the identification its surface composition.

The process of identifying and correlating known spectral signatures is at the core of the science of remote sensing. Understanding what the spectral information a single pixel represents provides the basis for understanding all pixels with the same spectral signature. Accurate classification of that signature is essential for effective remote sensing image interpretation because it serves the purpose of converting a detailed photograph into a wealth of spectral information.

Further, the amount and quality of information available within that pixel is entirely dependent on the characteristics of the sensor acquiring the data. Sensors with medium to low resolution, for example, may provide data adequate for regional and large-scale assessment. But large pixels produce spectral signatures that represent a mixing of many independent variables, rendering the image unreliable for most detailed land use or other thematic classification requirements. Sub-meter resolution is preferred when more accurate ground assessment is needed.

Hyperspectral sensors collect data in 200 to 900 narrow spectral bands. The adjacent nature of these bands provides a continuous spectral measurement across the electromagnetic spectrum and therefore is more sensitive to subtle variations in reflected energy. Images produced from hyperspectral sensors contain much more data than images from multispectral sensors and have a greater potential to detect subtle variations between features on the ground. While multispectral can be used to map forested areas, hyperspectral can be used to map tree species within the forest or identify disease conditions on those trees.

SIGNAL-TO-NOISE (SNR)

High SNR should be the goal of any hyperspectral sensor, but particularly with respect to airborne applications where available light varies. SNR is a complex wavelength-dependent function of the deployment conditions and the particular optical and electronic specifications of the system. The latter consideration determines how efficiently light is collected and sensed.
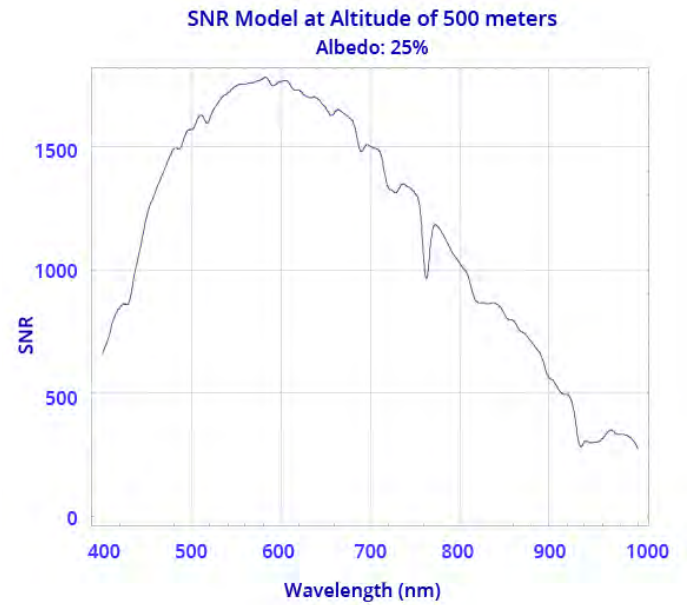
System deployment encompasses the target information that must be collected in a pre-defined time period. This includes the offset distance of the hyperspectral system from the scene, the required data collection rate (which may be limited by the speed of the aircraft), and the level of available illumination (as determined by the location and orientation of the sun). Other factors include the atmospheric state (which can attenuate the radiation reaching the hyperspectral system) and the optical (reflectance) properties of the target or sample being studied. This may also further limit the light reaching the sensor. Much of Headwall's work evaluating system-level SNR utilizes solar illumination. Such conditions may be accurately simulated by taking into account factors such as the solar parameters present (zenith angle and look angle of the sensor), as well as a full treatment of the atmospheric conditions including the chemical makeup of the atmosphere and the level of optical scattering over the whole wavelength range.

How does the actual design of a hyperspectral sensor affect these measurements? Of particular importance is the light-collection ability of the system as defined by the overall throughput of the system (F/#, or F-number) and the efficiency of each of the optical components. The available light reaching the hyperspectral system is then split into its spectral signatures at each position on the slit by the hyperspectral imager, so the reciprocal dispersion of the system (typically in units of nm/mm) is a critical parameter in determining system SNR. Also critical is the spectral bandwidth of the required measurement. Typically, the higher the required system bandwidth the more optical channels there are. However, this also means less light available in each of those channels, leading to a decrease in system SNR at that wavelength channel. Thus, a trade-off will often exist between competing system requirements and available system design parameters.

The final link in the chain determining SNR is the choice of focal plane array (FPA). Two regimes predominate in determining final system SNR. The first, which dominates at high signal levels, is the so-called *shot noise limit*. Here, many of the noise parameters of the FPA are irrelevant, and channel SNR is based on the limitations imposed by fluctuations of the photon field reaching the FPA pixel element and is determined purely by Poisson statistics. This is a fundamental limit based on the laws of physics. A simple calculation of the available SNR limit of a measurement system may be approximated by calculating the square root of the accumulated well depth of the super pixel of a spatial/wavelength channel after any spatial and spectral binning is imposed on the measurement.

The second regime occurs under conditions of low-level light detection. The accumulated specifications of the FPA, as defined by read noise, dark current, pixel non-uniformity and electronic noise, can all play a role in the final SNR determination. Consequently, the final SNR will be reduced further from the shot noise limit. We can make the universal statement that the SNR of a hyperspectral system will always be equal to or less than the shot noise limit at each pixel when one has determined how much light gets to that pixel.

Headwall's hyperspectral imagers are based on an all-reflective concentric design as shown below.

Not only is SNR maximized, but unwanted aberrations known as *keystone* and *smile* are eliminated by using concentric mirrors and high-performance diffraction gratings. The result is very high spatial and spectral resolution as discussed below, but also a very wide field of view that allows flight paths to be as efficient as possible.

Micro-Hyperspec®

Aberration-corrected imaging
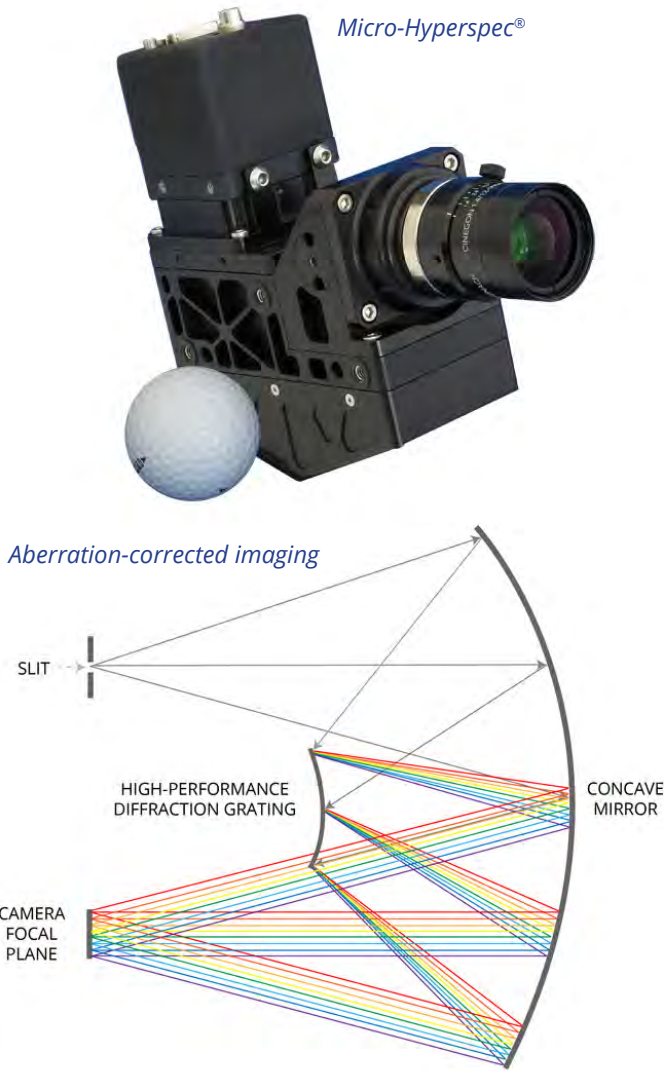
SPATIAL VERSUS *SPECTRAL* RESOLUTION

Hyperspectral sensors are routinely deployed not only aboard aircraft and UAVs, but commercial earth-orbiting satellites as well. For best resolution performance, a combination of these platforms is highly desirable. Orbiting sensors provide a continuous stream of imagery during the operational lifetime of the asset. While major advances have been made in optical, storage, and compression technologies, downlink bandwidth is still a major factor in the characteristics of the image data. The

two major contributing factors to image file size are *spatial resolution* and *spectral resolution*. Orbiting sensors are challenged to deliver both. High spatial resolution is achieved at the expense of available spectral bandwidth, as with **Worldview 1**, a panchromatic sensor with 50cm GSD. Conversely, acquiring broader spectral bandwidth is possible but at the expense of spatial resolution, as with **ASTER**, a 14-band sensor with GSD ranging from 15m to 30m. To circumvent the spatial and spectral limitations of orbiting sensors, hyperspectral sensors are typically mounted on aerial platforms, including manned and unmanned vehicles.

HYPERSPECTRAL APPLICATIONS

Because hyperspectral imaging presents a more data-rich mosaic for scientists, it has become a highly desired technology for applications within the remote-sensing realm. These applications include crop science, precision agriculture, mining and mineral exploration, petroleum exploration, ecology, disaster mitigation, and so many more. Typically, these applications are most efficiently done from the air. A tremendous amount of ground can be covered from a purpose-built UAV equipped with a hyperspectral sensor. This means that hard-to-reach territory is more accessible than ever for important environmental research. Headwall's Micro-Hyperspec® sensors (*see photo and diagram on page 4*) have been deployed extensively aboard multi-rotor UAVs to fly over very remote and harsh regions. Proper integration of the UAV with its sensor payload is a responsibility that Headwall assumes, reducing time-to-deployment by months.

Smaller and lighter UAVs mean a need for smaller and lighter payloads. Reduced size and weight, high SNR, and a wide field-of-view are characteristic of every Headwall airborne sensor. This means more efficient flight-paths for payload-restricted UAVs and more land that can be surveyed. Headwall's hyperspectral sensors also feature *Aberration-corrected optics*, meaning higher accuracy within that wide field-of-view.

The worldwide *precision agriculture* industry is vital on so many fronts because countries depend on the revenue derived from citrus, wine-grapes, nuts and other specialty crops. Also, famine relief is the byproduct of successfully planting and har-

vesting crops in harsh and unforgiving climates. Hyperspectral imaging is playing an increasingly large role here because economic and life-sustaining decisions need data that is precise and actionable.

The first application example involves the remote detection of water stress in a citrus orchard using leaf-level measurements of chlorophyll fluorescence. Because the relationship between tree-canopy temperature and stress levels is not clear-cut, other measurement techniques are needed. Short-term water deficits can affect plant health, so hyperspectral analysis of tree-tops can yield important information with respect to where, when, and how much irrigation is needed. A key pre-visual water stress indicator is chlorophyll fluorescence,

For applications ranging from precision agriculture to infrastructure inspection, hyperspectral sensors aboard UAVs like this multi-rotor Aibot X6 are used along with ground-truth instruments from ASD to provide precise, actionable image data (photo courtesy of Aibotix).

but its invisibility makes it very challenging to track. Hyperspectral imagers with high spatial and spectral resolution characteristics can be 'tuned' to seek out spectral signatures such as this.

Here, the hyperspectral imager extracted pure crown temperature, radiance and reflectance spectra to estimate chlorophyll fluorescence, visible ratios and structural indices for water stress detection. The instrument was designed for a 40cm resolution and 260 spectral bands in the 400-885nm VNIR spectral range at 1.85 nm/pixel and 12-bit radiometric resolution. This yielded a full width at half maximum (FWHM) spectral resolution of 3.2nm with a 12-micron slit, and 6.4nm with a 25-micron slit. The UAV consisted of a fixed-wing platform capable of carrying a 3kg payload for 1.5-hour endurance at 13.5kg takeoff weight (TOW). Data acquisition and onboard storage were set to 50 frames per second and an integration time of 18 milliseconds.

Another application estimated chlorophyll content in grape-wine leaves is feasible using leaf reflectance and transmittance in the VNIR-SWIR range from 400-2500nm. Because vineyards comprise complex heterogeneous canopies, effects caused by shadows and soil components as a function of sun angle and row orientation mean that the highest-possible resolution and good modeling is needed. This enables the removal of mixed pixels and shadow effects, making it possible to model the pure vine reflectance. The sensor was flown in the spectral mode of 260 bands at 1.85nm/pixel and 12-bit radiometric resolution, yielding a FWHM of 3.2nm with a 12-micron slit, and 6.4nm with a 25-micron slit in the 400–885nm region.

Data acquisition and storage on board the UAV was set to 50 fps, and integration time was 18ms. The 8-mm optics focal length yielded an IFOV of 0.93 mrad and an angular FOV of 50°, obtaining a swath of 522m at 53cm × 42cm resolution, resampled to 40cm for a flight conducted at 575m AGL altitude and 75 km/h ground speed.

ORTHO-RECTIFICATION

Ortho-rectification of the hyperspectral images is conducted using data acquired with an inertial measuring unit (IMU) installed on board and synchronized with the hyperspectral imager. A depiction of ortho-rectification is shown below.

The hyperspectral imagery acquired enabled pure vine identification for field validation purposes, successfully separating pure vine from shaded and sunlit soil reflectance in most cases, and obtaining pure vine reflectance, sunlit and shaded soil components separately. Single vines from each vineyard field were identified using automatic object-based crown detection algorithms.

Before   After
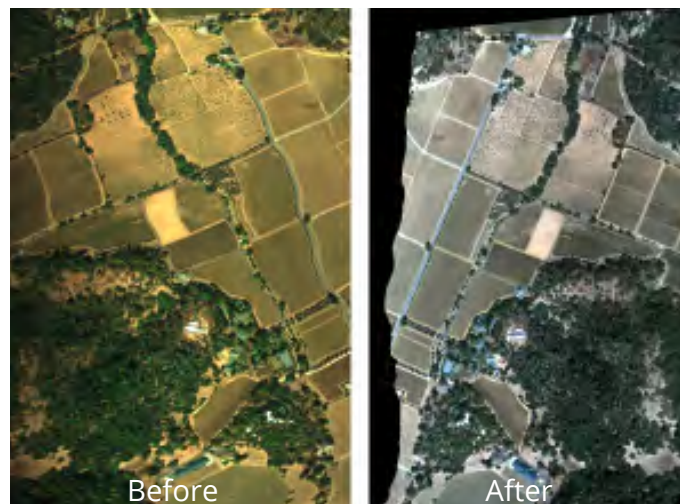
Headwall's Hyperspec® III software manages valuable post-processing tasks such as ortho-rectification to correct for variations in the surface of the earth and the tilt of the sensor.

Headwall's Hyperspec® III software is engineered and optimized for airborne applications and includes powerful tools that rapidly collect and process the incoming hyperspectral data. The software uses polygons for sensor control and data acquisition while also managing key post-processing tasks such as ortho-rectification. The software can also simultaneously manage multiple sensors. Screen images of Hyperspec® III are shown on Page 11.

GROUND TRUTH

While hyperspectral images contain a wealth of data, accurate interpretation of the image requires first-hand familiarity of the surface being analyzed. In the absence of this information, remotely sensed image analysis and classification is really no more than an inference or assumption regarding earth surface conditions nomatter how spatially or spectrally resolute the source image happens to be.

Ground-based reference measurements, known as ground truth, usually involve collecting information at or near the surface of the earth in support of an over-flight survey. The information may consist of several types of data acquired before, during, and after an image acquisition. This can assist with image analysis and interpretation, sensor calibration, and accuracy assessment of analysis results.

Ground truth measurements may involve a variety of spectroscopic, biochemical, geological, and biological observations that are tied to specific GPS coordinates within the image boundaries. Rock, soil and mineral samples may be collected for further analysis in the lab. Essentially, any detailed geo-spatial observations are useful but field-based spectral measurements of representative materials provide the key link between hyperspectral image data and the identity, properties and abundance of materials on the ground. In addition, spectral signatures of ground targets that are homogeneous at the scale of the imaging sensor and collected using ambient solar illumination can be used to convert hyperspectral images from radiance to reflectance.

A portable field spectroradiometer is a critical component of the remote sensing workflow process and hyperspectral image analysis. It provides for fast and accurate ground-level spectral measurement of targeted features for supervised classification, valuable ground-based atmospheric data for correction models, and serves as the basis for vicarious sensor calibration. These critical measurements tie actual surface and atmospheric conditions to a remotely-sensed pixel enabling accurate image interpretation and supervised thematic classifications.

ASD Inc. pioneered the science of field spectroscopy over 20 years ago. *FieldSpec 4* Hi-Res spectroradiometers are exceptionally advanced and rugged. ASD recognized that resolution provided in the SWIR range by standard array detectors used by other commercial portable spectroradiometers could not meet the high spectral resolution requirements of the hyperspectral remote sensing community. To overcome the array detector limitations, ASD incorporated an innovative scanning array system that provides the market with the only spectrographic system that maximizes the data points in the SWIR ranges (1001-2500nm) at 1nm intervals, totally independent of the sampling interval.

Combined with a 512-element silicon array for the VNIR range, the FieldSpec 4 provides the highest available resolution in a portable full range (350-2500nm) spectroradiometer, for spectral data that you can trust.

FIELD COLLECTION OF SPECTRAL SIGNATURES

Since field collected spectral signatures utilize ambient sunlight, their collection requires an awareness of the influences of the various sources of illumination, as well as atmospheric characteristics and wind. Instrument field of view, target viewing and illumination geometry, data collection time, and the spatial and temporal variability of the target characteristics also must be considered.

Two measurements are required in order to determine the reflectance of a material: the spectral response of a reference sample and the spectral response of the target material. The reflectance spectrum is computed by first dividing the spectral response of the target material by that of a reference sample. Then the resulting ratio is multiplied by the known reflectance of the reference sample.

Using this method, all parameters that are multiplicative in nature, such as the spectral irradiance of the illumination source and the optical throughput of the field spectrometer, and present in both the spectral response of a reference sample and the target material, are mathematically eliminated. Thus, when determining the reflectance of a material in the field, an inherent assumption is that the characteristics of the illumination are the same for both the reference and target materials.

Variability of the illumination characteristics between reference and target materials is the largest source of error in field collected spectral signatures. In the field, reference and target materials are both illuminated by three classes of illumination sources, each with its own spectral characteristics. Unless the target is shadowed, direct solar illumination is the dominant source of illumination. Parameters such as solar elevation angle and atmospheric conditions affect the overall intensity and spectral characteristics of direct solar illumination. Diffuse skylight illumination can contribute as much as 5-10% of the total illumination reaching a surface. At shorter wavelengths, diffuse skylight

can contribute as much as 20-25% of the total. Light scattered off the surroundings is the third source of illumination and one that is often overlooked. Surroundings scattered light can come from any object in the vicinity of the measured surface, with closer and larger objects having the largest contributions.

Variation in atmospheric water vapor often has the largest impact on field measurements of spectral signatures since water vapor has absorption features spanning the solar reflected region of the spectrum and varies both spatially and temporally. The presence of partial cloud cover is indicative of spatially and temporally variable atmospheric water vapor. Because of the large influence of water vapor on the atmospheric transmission, changes in atmospheric water vapor concentration between the time when the reference and target measurements are made will result in errors in the resultant field collected spectral signatures. Minimizing the length of time between the measurement of the reference sample and the target reduces this source of error.

By measuring the reference panel as a sample, the spectral changes associated with varying water vapor can be determined. If atmospheric conditions are stable, the observed reflectance of the reference panel is a flat spectrum with near 100% reflectance. If atmospheric conditions are unstable, the computed reflectance of the reference panel will vary over time and show absorption minima or maxima. This will depend on whether atmospheric water vapor is increasing or decreasing at the wavelengths corresponding to the water vapor absorption features. The maximum time difference between reference and target measurement is determined and field spectral signature collection procedures are modified accordingly.

In addition to the errors produced by time varying atmospheric water vapor, partial cloud cover also greatly increases the intensity of diffuse skylight illumination. This tends to "fill in" shadows and reduce the contrast between surfaces with dissimilar surface textures. In fact, it is possible to observe solar irradiance levels that are significantly higher than would be observed on a cloud-free day. If the goal is to collect field spectra for hyperspectral image calibration or interpretation, spectra should be collected under illumination conditions similar to those at the time the image was collected.

The spectral characteristics of the illumination scattered off surrounding objects are determined by their reflectance characteristics. In the case of a forest clearing, as much as 20% of the illumination in the 750-1200nm wavelength range can be attributed to sunlight scattered off the surrounding forest canopy. The person and the instrument making the measurement are an important source of surroundings scattered light. Objects in the surrounding area also affect the overall illumination of the target surface by obscuring a portion of the diffuse skylight and shading the target from direct solar illumination. The magnitude of both the diffuse skylight and light scattered from surrounding illumination components is determined by the solid angle subtended by these sources when viewed from the reference frame of the target surface. The closer the object and the more well illuminated the object, the larger the influence.

To demonstrate the effect of the surroundings, the reflectance of a stationary reference panel was measured on a day with a 40° solar elevation angle. The FieldSpec 4 spectroradiometer's fiber optic cable viewed the panel from the north to eliminate any shadowing of the target. During the initial reference measurement, the operator was kneeling below the level of the target so as to not influence the measurement. Additional panel spectral signatures were collected in order to document the influence of the operator on the panel's observed reflectance. In all cases, the operator was positioned such that there was no shadowing of the panel.

The largest influences occur when the operator was standing to the west and north of the target. In this position, the side of the operator facing the panel is well illuminated. Light scattered off the operator and onto the panel results in positive reflectance errors as high as 14%. The spectral characteristics seen in the plots below mirror the reflectance properties of the operator's clothing.
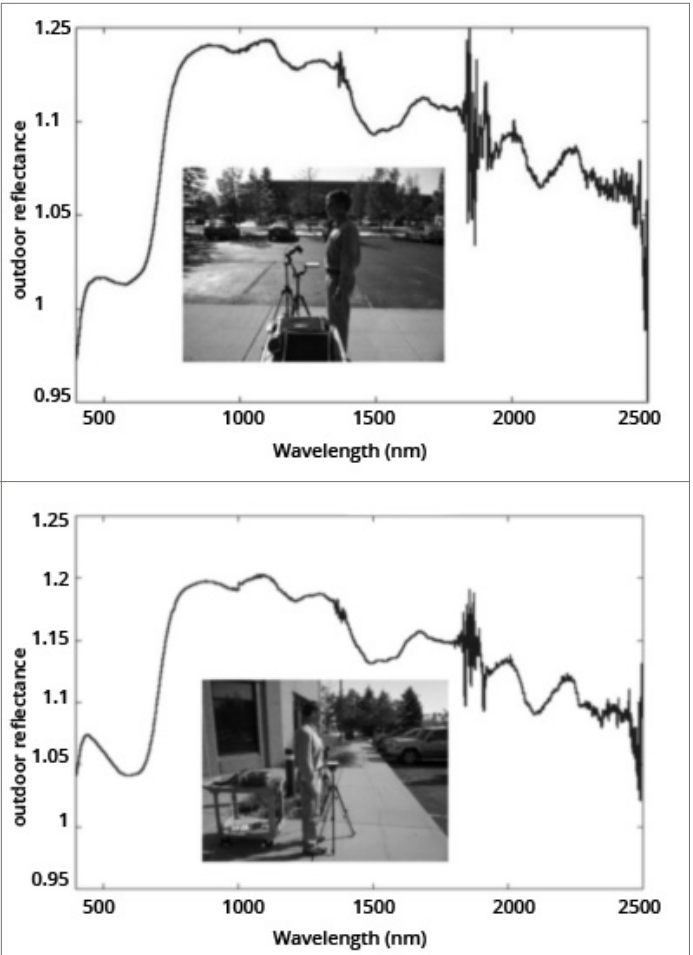
Panel spectral signature with the operator standing west (top) and north (bottom) of the panel.

As long as the position of the operator does not change between the measurement of the reference panel and the target, the effects seen in this example are minimized. It is only when the illumination impinging of the reference target is different from that illuminating the target that errors in the measured target spectral signature are introduced.

Since it is difficult to totally eliminate variations in the position of the operator, positioning the instrument's viewing optics as far away from the operator's body as is possible is optimum. In addition, holding the viewing optics to the side such that the operator's profile faces measured surfaces further minimizes the solid angle subtended by the operator. Thus, the operator should hold the FieldSpec 4 viewing optics at arm-length and to the side while maintaining a constant geometry between the sun and the measured surface.

The frequency of reference panel measurements should be adjusted to minimize the impact of factors influencing the intensity and spectral characteristics of the illumination. The major factors that determine the frequency of reference panel measurement are the solar elevation angle, atmospheric water vapor and clouds. In general, if the atmosphere is unstable, causing intermittent cloud formation, or if there is cirrus cover, it is possible to make reasonably good field spectral signature measurements as long as a reference measurement is taken just before the reflectance measurement.

On a clear day with stable atmospheric conditions, the interval between reference panel measurements is a function of the rate of change in the solar elevation angle. The rule of thumb is to make reference measurements at least every 10 minutes. Another consideration is the expected accuracy of the reflectance measurement. For modest requirements, a longer interval is available between reference measurements. If errors on the order of one percent are required, then within one hour of noon on a clear and stable day it is possible to allow 10 minutes between white reference measurements. For the same error requirement, at two hours from local noon, three to four minutes between measurements would be necessary. At three hours, reference measurements would need to be made every one to two minutes.

HYPERSPECTRAL & GROUND-TRUTH

For a wide range of applications, the combination of airborne hyperspectral with ground-based instruments like FieldSpec 4 non-imaging hyperspectral radiometers represent an optimal solution. Calibration of results is fundamental to hyperspectral data collection, as explained in the brief case studies noted on Page 10.

To get started with Headwall and ASD, full contact information for both companies can be found on the back page of this document. Application engineers stand ready to discuss your specific needs in full detail to arrive at an integrated solution.

Predicting Soil Strength with Remote Sensing Data - Jon Wende, Naval Post Graduate School, R.C. Olsen, C. Bachmann advisors (customers of Headwall and ASD).

Predicting soil strength from hyperspectral images enables amphibious planners to determine

trafficability in the littorals. Trafficability maps can be generated and used during the intelligence preparation of the battlespace, allowing amphibious planners to select a suitable landing zone. Airborne hyperspectral images along with ground truth data was collected from shallow water lagoons, beach-front, vegetation, and anomalies such as World War II relics. Beachfront hyperspectral data obtained on-site was used as a reference library for evaluation against airborne hyperspectral data and ground truth data in order to determine soil strength for creating trafficability maps. Evaluation of the airborne hyperspectral images was accomplished by comparing the reference library spectra to the airborne images. The spectral angle between the reference library and airborne images was calculated producing the trafficability maps that amphibious planners can use during intelligence preparation of the battlespace. Three ASD FieldSpec instruments were used throughout the project.

Wyoming Assessment Project and Remote Sensing of Leafy Spurge - *A.P. Williams, D. J. Kazmer.*

A fundamental research need in leafy spurge and invasive plant management as a whole is cost-effective, large-scale mapping of plant populations. Hyperspectral airborne data was acquired over a 25-square-mile study area in Crook County, Wyoming. ASD's FieldSpec spectroradiometer was used to collect ground calibration and reflectance data of leafy spurge, other vegetation, and soils. These spectra were used to perform spectral mixture analysis on the hyperspectral scene. A major advantage of this technique is that it can effectively *unmix* a pixel and provide an estimate of the real extent of leafy spurge within the pixel.

Comparison of Remote Sensing Based Analysis of Crop Disease by Using High Resolution Multispectral and Hyperspectral Data – Case Study: Rhizoctonia Solani in Sugar Beet - *R. Laudien, G. Bareth, R. Doluschitz, Department of Agricultural Economics, Division: Agricultural Informatics and Farm Management, University of Hohenheim, Stuttgart (Germany).*

High resolution multispectral satellite and hyperspectral aerial remote sensing data was used to detect and analyze a fungal sugar beet disease in a study area of Southern Germany. A FieldSpec hand-held non-imaging hyperspectral radiometer

was used to collected reference data to differentiate between healthy and unhealthy plants, and to create classifications used to train the supervised classification sets from the imagery. Results were correlated with spectral and hyperspectral vegetation indices. Infected sugar beets were identified by analyzing the different data sets and calculating vegetation indices and then classifying them into several vitality classes.

SUMMARY

Airborne hyperspectral imaging is an exciting, evolving technology for the remote-sensing market. UAVs, fixed-wing aircraft, and earth-orbiting satellites are all perfect platforms for small and light hyperspectral imagers that provide continuous spectral data for everything within the field of view. Headwall's precision-packed hyperspectral sensors are based on aberration-corrected optics to deliver high SNR plus excellent spatial and spectral resolution across a very field of view.

Ground-based reference measurements can be used to verify airborne hyperspectral data, which means the combination represents a very powerful solution for the remote-sensing community. As leaders in their respective markets, Headwall and ASD understand the relationship between ground-truth and hyperspectral. This collective knowhow can be applied to any remote-sensing application and we welcome the opportunity to work with you!

To learn more about hyperspectral and ground-truth technology, please contact either Headwall or ASD using the information on the back page of this document. Application engineers stand ready to discuss all aspects of these topics with you.

## Headwall's *Hyperspec® III* Airborne Application Software Screen Images

Hyperspec III application software with SpectralView® functionality provides a complete suite of powerful tools for data collection, management, and post-processing.
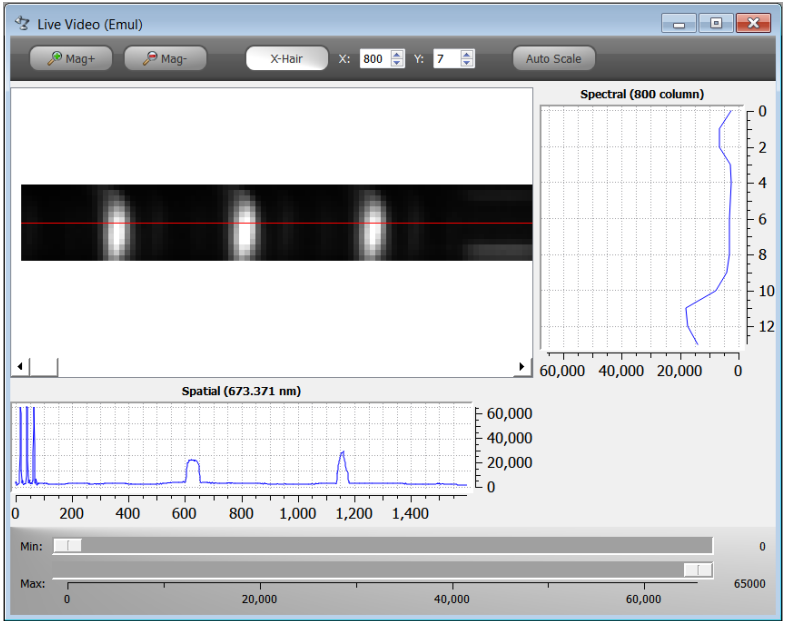
Application Module for control of airborne hyperspectral instruments.
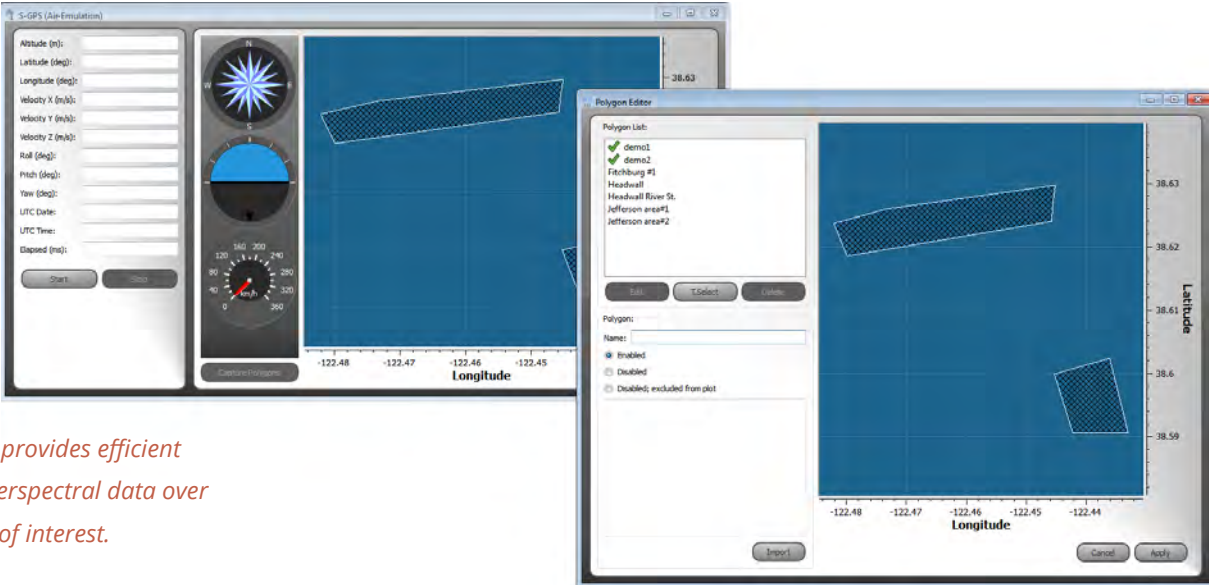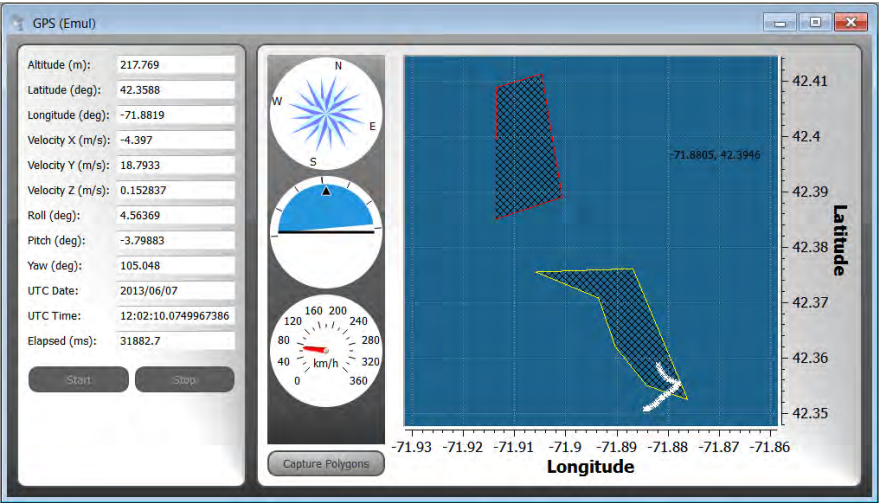
Polygon editor provides efficient capture of hyperspectral data over selected areas of interest.
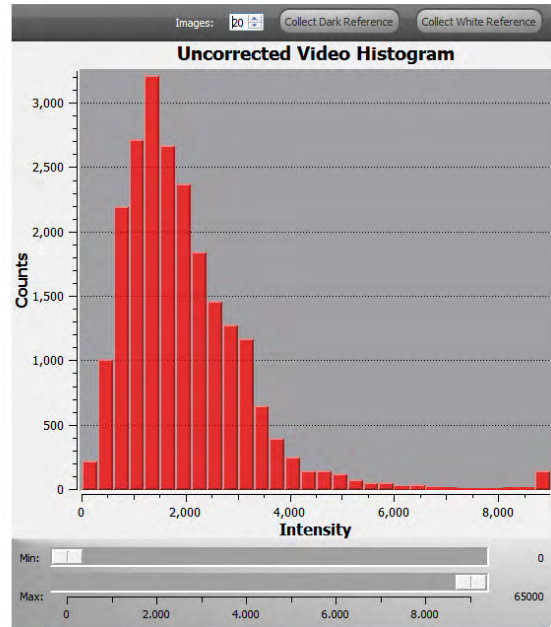
Waterfall display: Three wavelength (RGB) composite image; histogram defines min/max intensity distribution for optimizing quality of data collection.

HYPERSPECTRAL RANGES

LWIR 8-12 µm

MWIR 3-5 µm

SWIR   950-2500 nm

NIR   900-1700 nm

Ext. VNIR   550-1650 nm

VNIR   380-1000 nm

VIS   380-824 nm

UV-VIS   250-500 nm