Operational Multi-Angle Hyperspectral Sensing for Feature Detection

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ABSTRACT

Remote sensing results of land and water surfaces from airborne and satellite platforms are dependent upon the illumination geometry and the sensor viewing geometry. Correction of pushbroom hyperspectral imagery can be achieved using bidirectional reflectance factors (BRF's) image features based upon their multi-angle hyperspectral signatures. Ground validation of features and targets utilize non-imaging sensors such as hemispherical goniometers. In this paper, a new linear translation based hyperspectral imaging goniometer system is described. Imagery and hyperspectral signatures obtained from a rotation stage platform and the new linear non-hemispherical goniometer system shows applications and a multi-angle correction approach for multi-angle hyperspectral pushbroom imagery corrections. Results are presented in a manner in order to describe how ground, vessel and airborne based multi-angle hyperspectral signatures can be applied to operational hyperspectral image acquisition by the calculation of hyperspectral anisotropic signature imagery. The results demonstrate the analysis framework from the systems to water and coastal vegetation for exploitation of surface and subsurface feature or target detection based using the multi-angle radiative transfer based BRF's. The hyperspectral pushbroom multi-angle analysis methodology forms a basis for future multi-sensor based multi-angle change detection algorithms.

Key Words: hyperspectral sensing, subsurface feature detection, surface feature detection, radiative transfer modeling, shallow water sensing & bathymetry, bidirectional reflectance factors, goniometers, airborne operational sensing, multi-angle hyperspectral signatures.

1. INTRODUCTION

1.1 Background

Future satellite, airborne as well as ship and land based sensing platforms will utilize multi-sensor and multi-angle hyperspectral pushbroom sensors and platforms. Existing satellite imagers such as MISR and AirMISR [1, 2] are commonly known multi-angle Imaging SpectroRadiometer systems. Airborne point cloud stereo sensing [3] as well as building multi-directional spectral signatures [4] are being used in earth remote sensing. The calculation of the bidirectional reflectance distribution function (BRDF) [5] and the bidirectional reflectance factor or BRF [6] have been accomplished using various sensing platforms, including ground based sensing platforms [7] as well as from ships or small vessels [8,9].

Modern lightweight hyperspectral pushbroom imaging systems allow the creation of multi-angle hyperspectral signatures of earth features and man-made targets using specially designed goniometers. These are helping to develop new data analysis capabilities and facilities [10]. The work reported below involves the use of a relatively new multi-platform hyperspectral imaging system designed and integrated [11 ,12] for water and coastal vegetation dysfunction assessments [13] and is intended to be used in a hyperspectral goniometer imaging facility [14] being developed in Marine and Environmental Optics Lab. For example, the hyperspectral imaging system described by Bostater, et al. [8, 9, 11, 12] was used not only from an airborne platform, but also from the ground using a fixed sensor mount (tripod based) and a rotation stage to make bidirectional reflectance distribution function (BRDF's) measurements in order to help characterize reflectance of weather oil on the water surface. These measurements were needed to help understand the influence of weathered oil thickness, illumination geometry and viewing geometry, as well as wavelength upon weathered reflectance signatures and related coastal vegetation dysfunction.

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2. TECHNIQUES & METHODS

2.1 Goniometer rotation system for weathered oil operation flight data

As depicted below, during February thru May, 2011 signatures obtained from the HS imaging system mounted on a goniometer tripod with a rotation stage. The mounted hyperspectral imager developed by Bostater [11,12] was used to image large *in-situ cuvettes* in a water tank (Figure 1) and in a natural coastal canal environment to help understand the BRF of weathered oil. Results were used to select optimal bands and channels for weathered oil feature detection in littoral coastal waters and coastal vegetation.

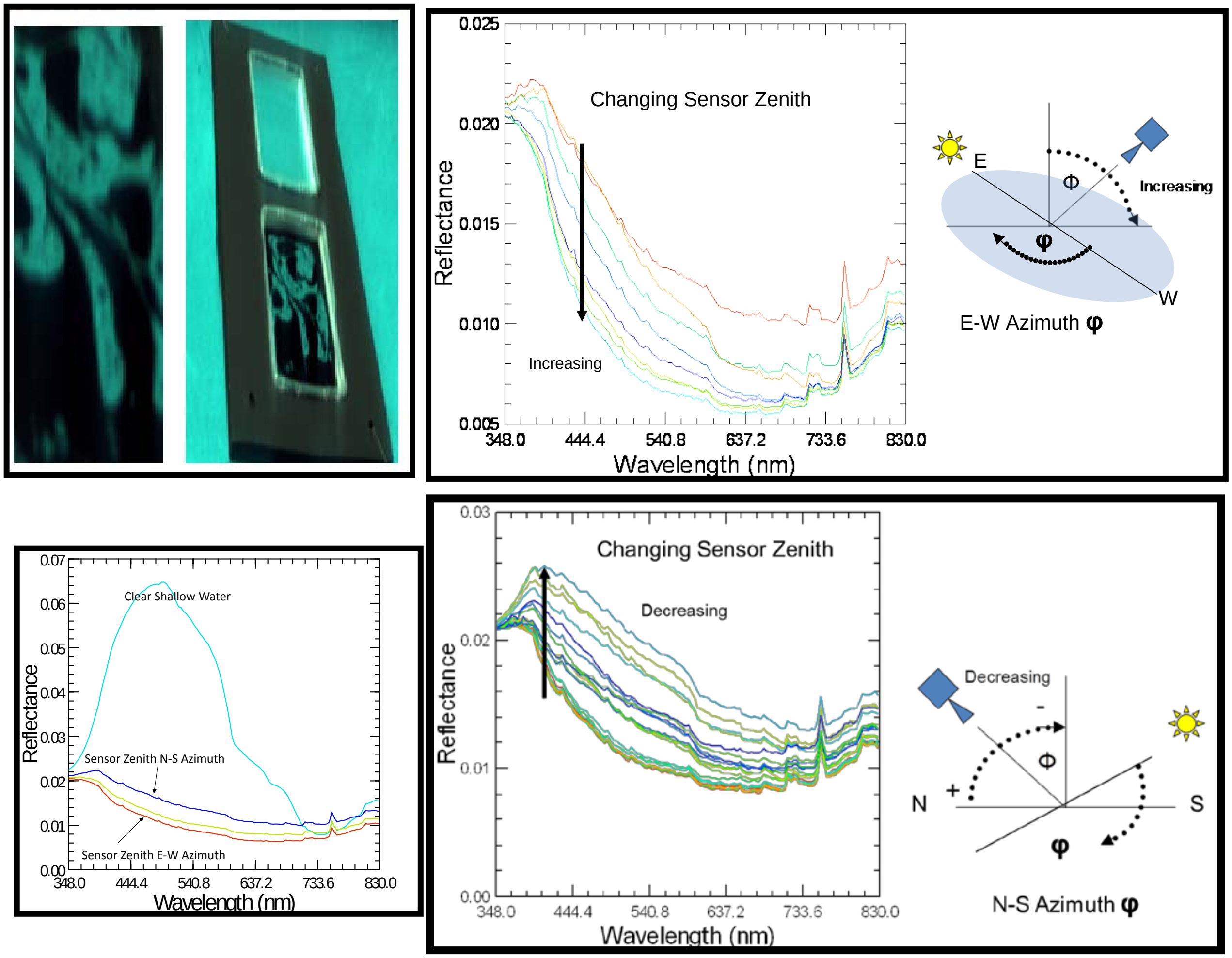

Figure 1. *In-situ cuvettes* (upper left) and resulting bidirectional reflectance factors (BRF) of weathered oil using the hyperspectral imaging system mounted on a rotation stage. The *sensor azimuth* plane was in the east-west (upper right) and north-south azimuth (lower right) plane of the solar disc arc as indicated. Note the spectral signature *shape* differences between the sensor azimuth positions and sensor zenith angles, suggesting the ability to distinguish clear shallow water and turbid water from the weathered oil in littoral shoreline environments (lower left). Measurements were made with minimal solar zenith changes ($<1^0$) using the HS imager.

The above BRF's were collected in order to be used to help in the operational collection of airborne hyperspectral imagery over near shore littoral zones in the Northern Gulf of Mexico, after the Deepwater Horizon oil and gas releases were contained at the source. A project, funded by BP through the Florida Institute of Oceanography was designed to image subsurface weathered oil in the event that the released material would come ashore southern Florida's panhandle region and shorelines as shown in Figure 2 (lower right) from airborne operational flight lines collected in March 2011.

A shipboard goniometer hyperspectral imagery was also used to collect multi-angle hyperspectral signatures February, 2011. The ship mounted system is shown in Figure 2 (upper right). This system was used to collect hyperspectral *multi-angle shoreline signatures* in Barataria Bay in an area of known (red shoreline indicated areas) based upon ground reported visual shoreline assessment (A and B) teams on vessels. HS imagery (C,D) with ~4-6 mm GSD was collected at a weathered shoreline. Airborne HS BRF cube of an oil impacted shoreline is shown in (D) below using the HS system.

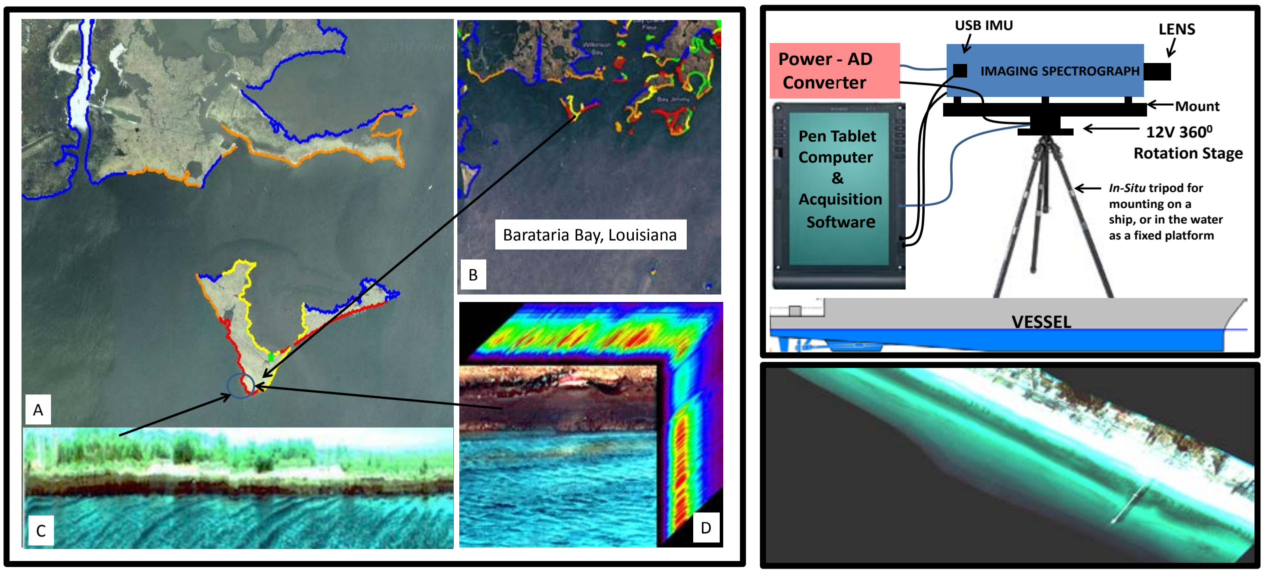

Figure 2. A ship mounted rotation goniometer (upper left) was used to acquire multi-angle BRF weathered oil signatures along a Barataria Bay, Louisiana, USA impacted shoreline indicated in (A) and (B) within the circled area. Resulting bidirectional reflectance factor (BRF) signatures were calculated as indicated in the above RGB image (C) and the BRF hyperspectral cube (D). The lower right image is an airborne HS image of a flight line showing a BRF 3 band RGB image along the Florida Panhandle, collected March, 2011 using the same hyperspectral imager [8,9,10,11].

Figure 3 below shows the shoreline multi-angle hyperspectral data acquisition multi-angle acquisition methodology aboard a vessel using the rotation stage HIS system in order to calculate the bidirectional reflectance factors (BRF) as described originally by Slater [6] using a radiance sensor and a wavelength calibrated Lambertian grey panel. The approach utilizes grey panel reflectance panels used in the goniometer based BRF HS imaging system.

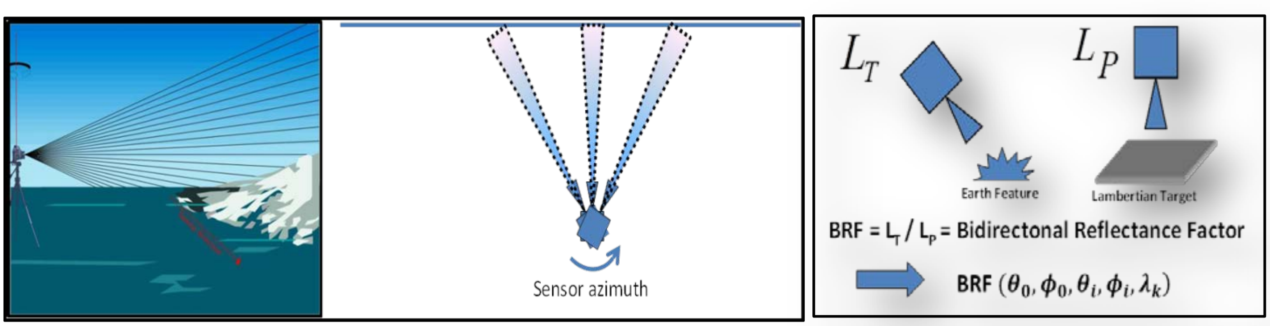

Figure 3. Operational multi-angle hyperspectral signature acquisition methodology used aboard a vessel as depicted above. The methodology allows for creation of signature libraries for use in developing BRF algorithms [8,9] used in airborne multi-angle flight missions in littoral zones. The approach uses sensor azimuth, senor and solar zenith angles.

2.2 Translation based goniometer system

There is a need to develop methods for (a) acquiring and (b) correction multi-angle hyperspectral imagery collected from pushbroom hyperspectral sensing systems. Traditional hemispherical goniometers [5,10,14,15] are limited in their ability to utilize *pushbroom imaging* systems by the nature of existing system designs. Correcting HS imagery for multi-angle sensing angles is important now and will continue to be needed. To date, sensing systems such as MISR and airMISR have be used for multiple channel radiometer corrections for atmospheric properties. To meet the need for HS imagery, a system was designed to horizontally translate a HS pushbroom imager [11,12] *and* to collect HS imagery at different sensor and illumination geometries (sensor zenith angle, sensor azimuth angle, solar zenith and azimuth angles). The system utilizes a total of 3computerized stepping motors that move the HS imaging system as shown in figure 4.

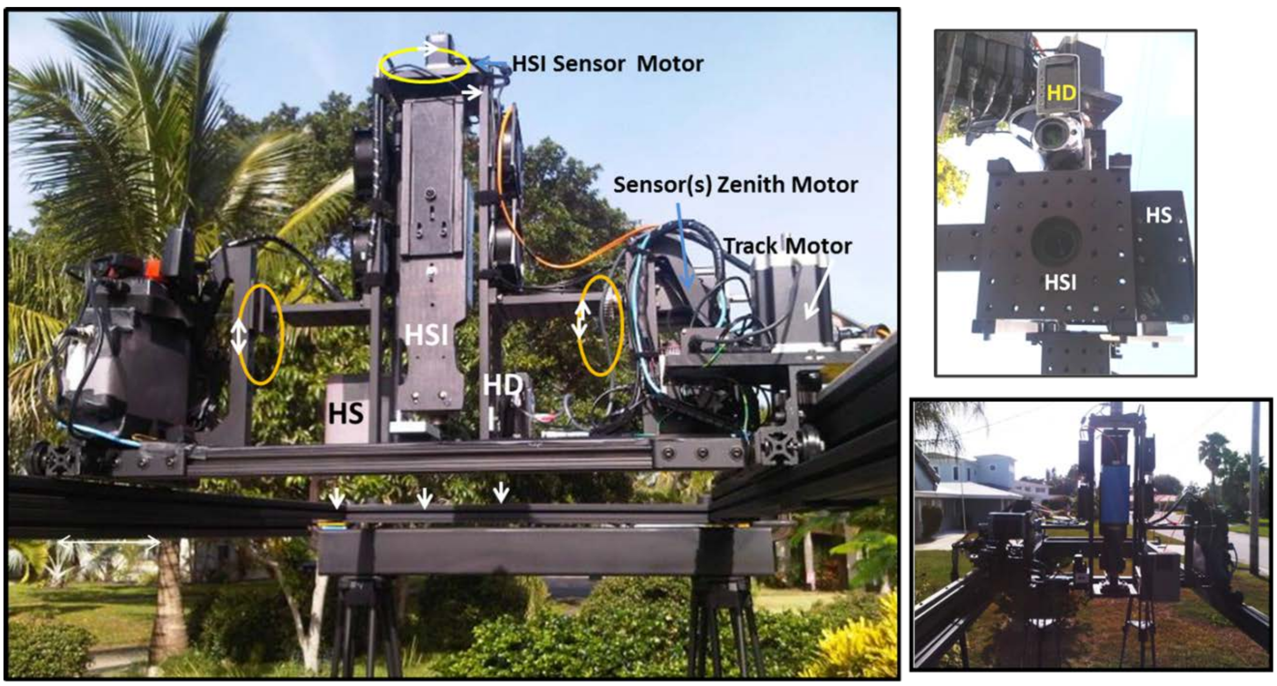

Figure 4. A multi-angle translation based goniometer system for changing the sensor zenith angle, azimuth angle and vertical HS sensor rotation along the vertical axis (***for snapshot HS image acquisitions***). The stepping motors are computer controlled for rapid pushbroom image acquisitions. The translation goniometer system is a multi-sensor system since the sensing stage or mount also incorporates a high definition video camera and a solid state spectrograph (SE590). The HS imager was built by Bostater [11,12] and is also easily mounted on a vessel or airborne sensing platform [8,9] as described above.

The height of the translation track can be modified and the track is mounted on wheels in order to rotate the system into user specified *sensor azimuth angles* along a given track line, similar to the flight track of an aircraft, the directional track of a vessel or the ground azimuth track of a satellite. The sensor zenith angle can vary from ±50 degrees (see figure 5). The azimuth angle of the imagery collected is changed by rotating the track system using attached wheel bases. The solar zenith angle is selected based upon operational mission design (airborne or satellite) time. The HS imager collects 64 to 1024 channels using CCD binning. The coastal vegetation shown below was scanned using 130 narrow spectral channels from approximately ~400 to 830 nm. The across track imagery is acquired with 1376 spatial pixels. The SE590 solid state spectrograph collects 252 channels of narrow, high sensitivity signatures of targets along the tracking direction (moving) or at a fixed point (stationary). The SE590 and the HSI system are bore sighted using a 532 nm laser. The location or position of the laser is also determined within the high definition (HD) video imagery. The HD video is collected continuously during HS image acquisition and operation of the SE590. Calibration of the HS imagery is accomplished using calibration spheres and newly developed large scale calibration targets as shown in Figure 6 below. Calibration targets are available from www.bostater.info.

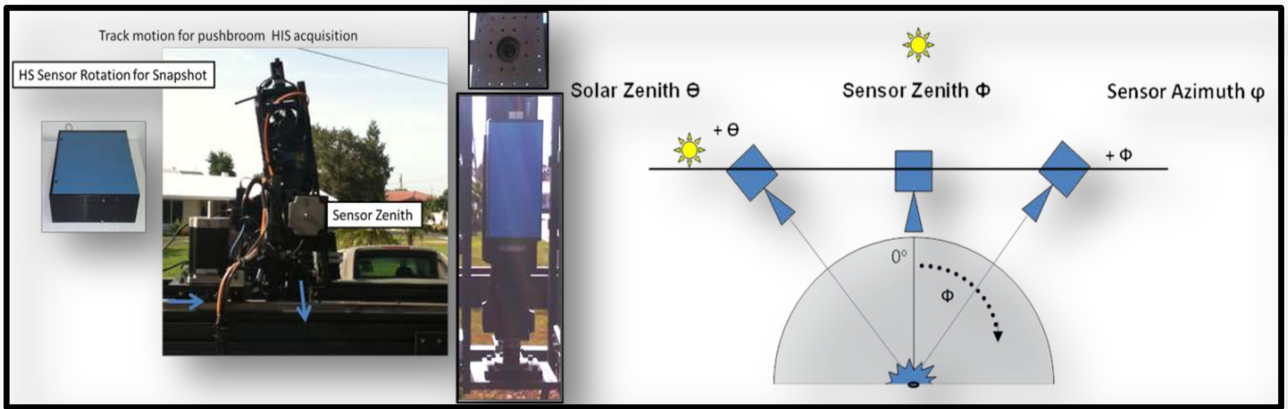

Figure 5. Side view of the translation based goniometer ad schematic showing the pushbroom sensor operation at different sensor zenith angles along a sensor azimuth track. The blue arrows (left) show the sensor zenith angle and horizontal track movement for HS image collection. The schematic on the right shows th operation along a track at any specified zenith angle (zero to 50 degrees) over a earth feature or target. The target is "imaged" at a given sensor zenith as the pushbroom sensor systems are translated along the track. Thus, pushbroom multi-angle hyperspectral images were collected using the sensing system developed by Bostater [11,12].

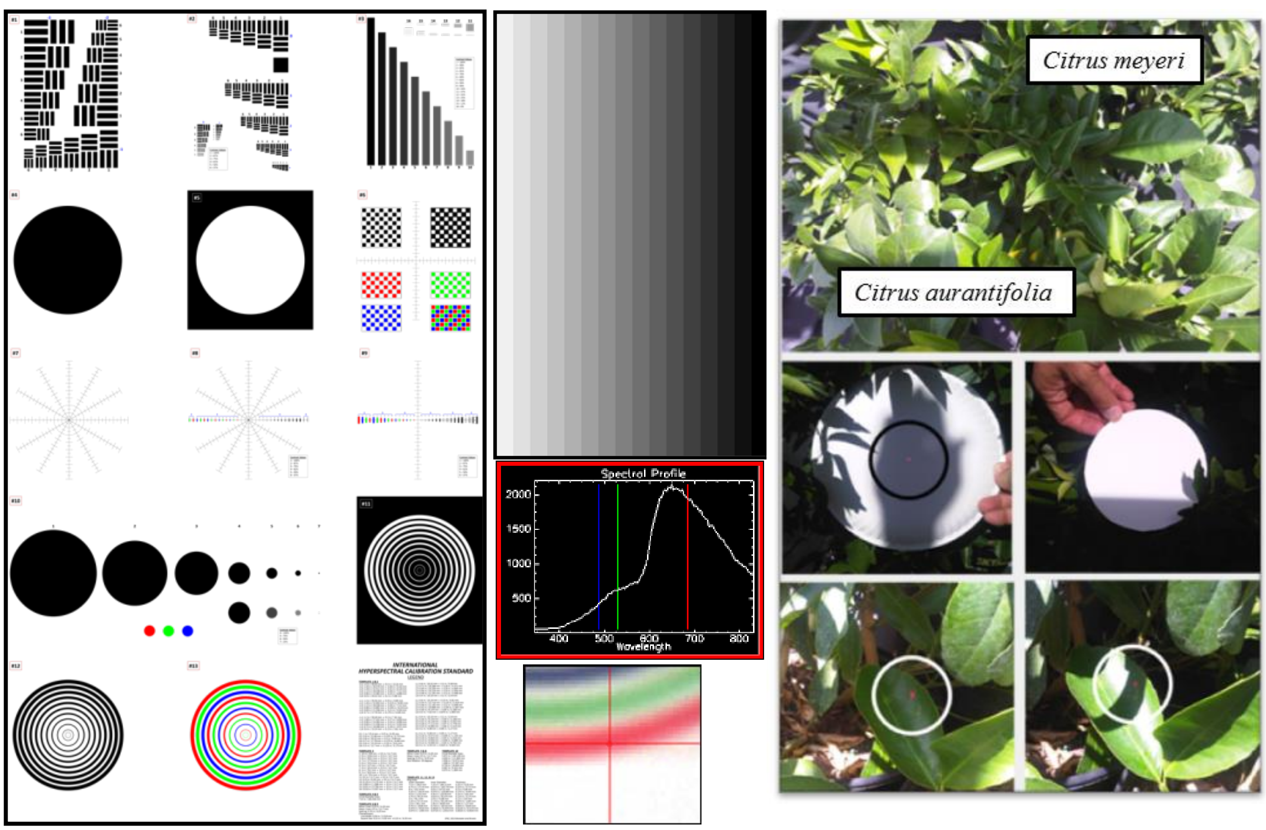

Figure 6. Large scale (~1 x 3 m) hyperspecral calibration target (left) and grey contrast target (middle) used for adjusting focus, f-stop, translation motion speed and Bayer color spectrum (middle signature) of the HD video using the spectral color rings. The HS imaging system and the solid state spectrograph are boresighted using a 532 nm laser (bottom right) mounted on the spectrograph. Image and spectrograph nadir spot areas (GSD) are shown (right middle) for the 2 coastal vegetation species indicated in the above image (right).

2.3 Selected Translation based goniometer BRF system results and analysis procedure

Multi-angle spectral reflectance signatures (BRF's) obtained from the SE590 and the HS imaging system can be used to correct or normalize hyperspectral images by utilizing "anisotropy factors" [10,15] referenced as ANIF's. These are calculated using a multiangle BRF (reflectance signature) normalized to the Nadir viewing BRF (sensor zenith reflectance signature). Thus, bidirectional reflectance information is obtained from the translation goniometer where the feature or target multiangle radiance signature is collected and then normalized to a near simultaneously measured Lambertian panel (Spectralon grey panel and calibration coefficents). The mutluangle BRF's are then normalized the nadr viewing geometry BRF. This approach allows for the normalization or "correction" of multi-angle HS imagery in order to match (within known errors) the nadir viewed HS image. In addition, the approach allows for calculation of ANIF hyperspectral images wherein the ANIF images contain unque information concerning the spatial coherence or lack thereof of the ANIF factors within the image of a ground based feature or target. Example of the SE590 BRF's are shown below for the 353 degree sensor azimuth (coincident with the TERRA and AQUA satellite track over Florida and the Gulf of Mexico), on August 28,2013 for 2 mixed coastal vegetation species *Citrus meyeri and aurantifolia*. These results suggest BRF changes with sensor zenith viewing geometry as expected. Of particular interest however is the *change in "spectral shape"* with important implications for band ratio or derivative imaging spectroscopy algorithms and related optimal band selection for remote sensing algorithms using operational multi-angle remote sensing.

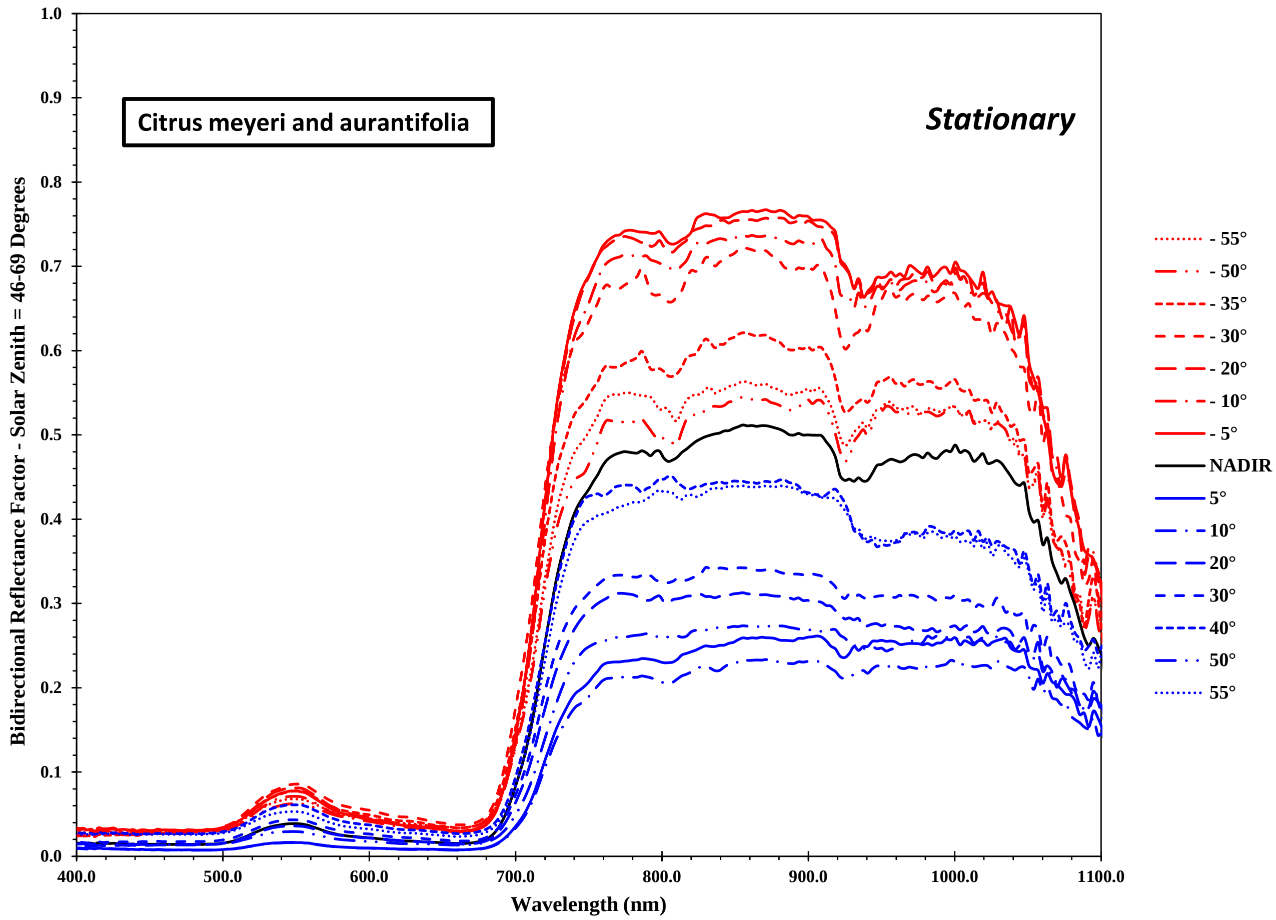

Figure 7. Example multi-angle bidirectional reflectance factors (BRF's) obtained August 28, 2013, AM, using the translation goniometer. Sensor azimuthal direction was in the plane of the AQUA and TERRA satellites (352 degrees) over Florida and he Gulf of Mexico littoral areas. Sensor zenith angles ranged from -55^0 to 55^0 degrees. The nadir viewing BRF is quite different from the multiangle sensor results with respect to spectral shape. These signatures form the basis of advnced ***coastal vegetation dysfunction*** sensing algorithms [13] using multi-angle imaging spectroscopy based upon multi-angle signatures.

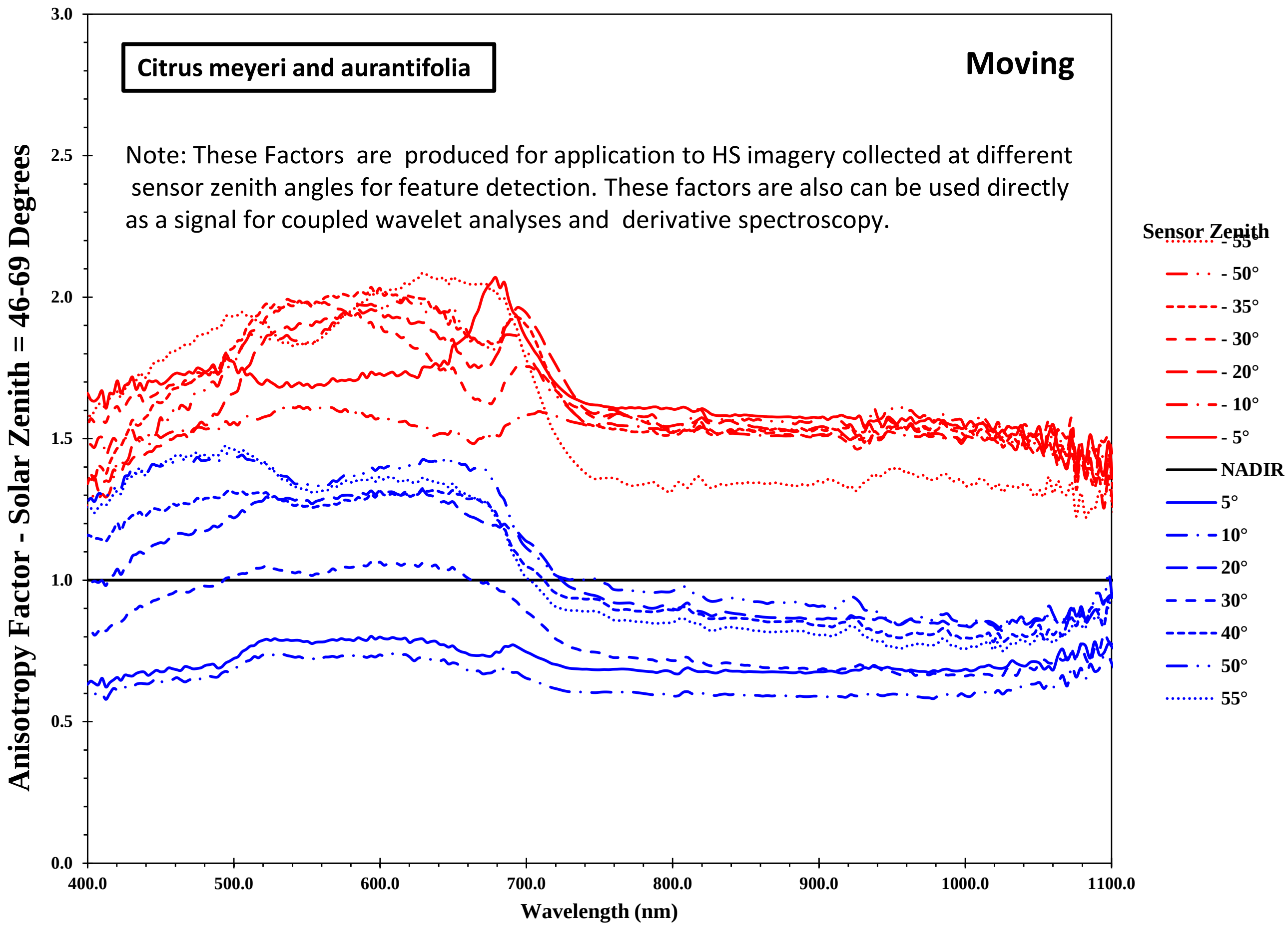

Figure 8. Anisotropy factor (ANIF) signatures calculated for correcting or normalizing hyperspectral pushbroom imagery described below. These multi-angle ANIF values at each chnnel can be applied to hyperspectral imagery in order to demonstrate how multi-angle hyperspectral imagery can be corrected for multi-sensor sensor zenith and azimuthal directions in operational multi-angle airborne or future satellite remote sensing system information. BRF's utilized to calculate these ANIF multi-angle signatures were collected using the transaltion based goniometer in the collection scheme depicted in figure 9 below.

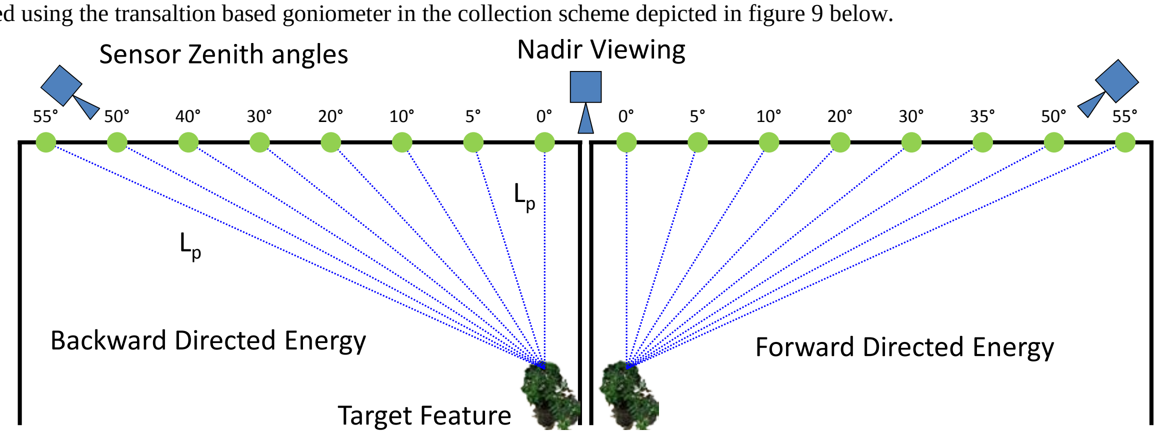

Figure 9. The translation based hyperspectral imaging goniometer (figure 4,5) data collection scheme used to collect SE590 and HSI system [11,12) images at each angle shown above in the backward and forward directions with reference to the target or feature. BRF and ANIF multi-angle signatures shown above were calcaulated at the shown sensor zenith angles at a sensor azimuth of 352^0 degrees.

2.4 Goniometer BRF and ANIF analysis framework

Figure 10 presents an operational framework for multi-angle hyperspectral remote sensing mentioned above where the inverse of an ANIF is applied to correct an off-nadir image (either forward or backward directed viewing as described in figure 9). Prior to applying the hyperspectral ANIF signature correction, the nadir viewing hyperspectral image and the off-nadir sensor zenith angle hyperspectral image needs to be co-registered or geo-registered using *image to image registration* techniques. The accuracy or quality of the image to image registration can influence the final result that is essentially a newly calculated or estimated nadir image using the multi-angle image. Care must be taken in this registration process. As shown in Figure 11, the ANIS signatures selected within a region of interest can be applied to specific areas with multi-angle off-nadir imagery. Apparent noise in the ANIF will also influence the final results but the technique holds great promise for developing "***hyperspectral multi-angle change detection algorithms***" that can be based upon combinations of (a) sensor viewing geometries, (b) sensor azimuth geometry as well as solar zenith and azimuth angle effects for feature and target detection from hyperspectral and multi-sensor system and platforms.

Operational Multi-angle Hyperspectral Image Analysis Framework

The ANIF hyperspectral signature and resulting image is calculated by normalizing the BRF signature at each wavelength with respect to the nadir BRF_n. As a dimensionless quantity, the ANIF represents the deviation of reflectance from that measured at nadir per wavelength and is written mathematically as:

$$\mathrm{ANIF}\left(\theta_i, \varphi_i, \theta_r, \varphi_r; \lambda_k\right) = \frac{\mathrm{BRF}\left(\theta_i, \varphi_i;\ \theta_r, \varphi_r;\ \lambda_k\right)}{\mathrm{BRF_n}\left(\theta_i, \varphi_i;\ \theta_n, \varphi_r;\ \lambda_k\right)}.$$

Using the ANIF hyperspectral image cube, an HS image correction can be calculated by applying the inverse of the ANIF signatures to the collected HIS at any given sensor azimuth (ϕ) plane and sensor zenith (θ) plane per wavelength. Mathematically, multi-angle the approach is written as:

$$\mathrm{HSI_{COR}}\left(\theta_i, \varphi_i, \theta_r, \varphi_r; \lambda_k\right) = \mathrm{HSI}\left(\theta_i, \varphi_i, \theta_r, \varphi_r; \lambda_k\right) \frac{1}{\mathrm{ANIF}\left(\theta_i, \varphi_i, \theta_r, \varphi_r; \lambda_k\right)} ,$$

where :

$\mathrm{HSI_{COR}}\left(\theta_i, \varphi_i, \theta_r, \varphi_r; \lambda_k\right)$ = corrected multiangle signatures in a hyperspectral image.

There are numerous reasons why the BRF, BRDF and ANIF signatures are important, but the approach described is being used in this research relates to developing ***multi-angle change detection of features and targets***. The approach thus utilizes multi-angle corrected imagery in order to remove sensor and illumination geometry effects for coastal vegetation dysfunction monitoring, water surface and subsurface feature and detection in coastal ecosystems.

Note – the authors are aware of no previous studies where a hyperspectral ***imaging*** system has been used with a goniometric device in order to calculate BRF's or BRDF's as a multiangle hyperspectral image correction method. The method *requires image to image registration* of multi-angle hyperspectral imagery.

Figure 10. A description of a hyperspectral multi-angle (off-nadir) image correction framework that utilizes co-registered images for calculating a hyperspectral anisotropy factor (ANIF) image and application of this result to the off-nadir imageery. An example of the the off-nadir multi-angle hyperspectral image analysis approach is shown below.

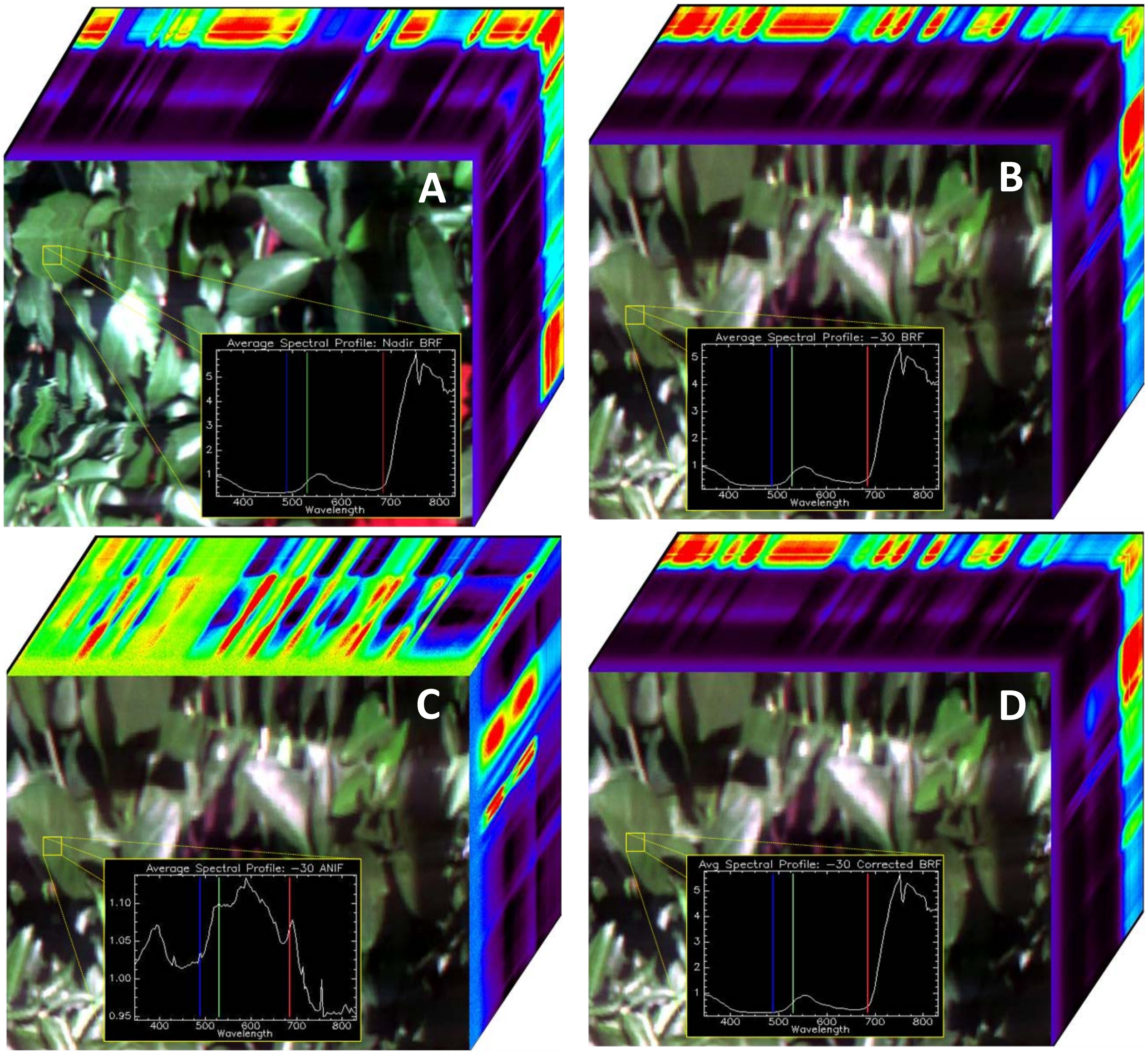

Figure 11. A hyperspectral image cube of coastal vegetation *Citrus meyeri and aurantifolia* collected at nadir and the -30^0 sensor zenith and 45^0 degree sensor azimuth direction *scaled* reflectance image. Image (A) is the nadir *scaled* reflectance image and the region of interest where the sclaed reflctance image (B) at -30^0 is used to calculate the ANIF for the region of interest as shown in the hyperspectral (ANIS) image cube (C). The region of interest ANIF is applied to the whole scene as shown in the *scaled* hyperspectral image cube (D) result. Hyperspectral imagery was collected using HS pushbroom system developed by Bostater [11,12].

2.5 Operational Mission Planning Considerations

Figure 12 below shows schematic examples (b,d) of using hyperspectral multi-angle operational data in terms of the sensor azimuth angles airborne platforms and hyperspectral imagery. In addition, previous images in this paper presented azimuth multi-angle imagery collected from vessels [9,11,12,16]. Airborne operational flight planning mission flight tracks in Florida generally utilize sensor azimuth angles that are in the plane of the solar disc (east-west directions) and sensor zenith angles selected at mid-morning and mid-afternoon solar zenith angles in order to minimize sun glint effects when water surface or features are being studied. Additionally, Florida Atlantic ocean and near coastal waters and lagoons are flown in the sensor azimuth in order to coincide with the orbital tracks of MODIS and TERRA satellite pass tracks of ~ 252 or 172^0 in the NS directions so that the sensor azimuth imagery is more readily comparable to the MODIS and MISR satellite sensors as depicted (a,c) in figure 12 below.

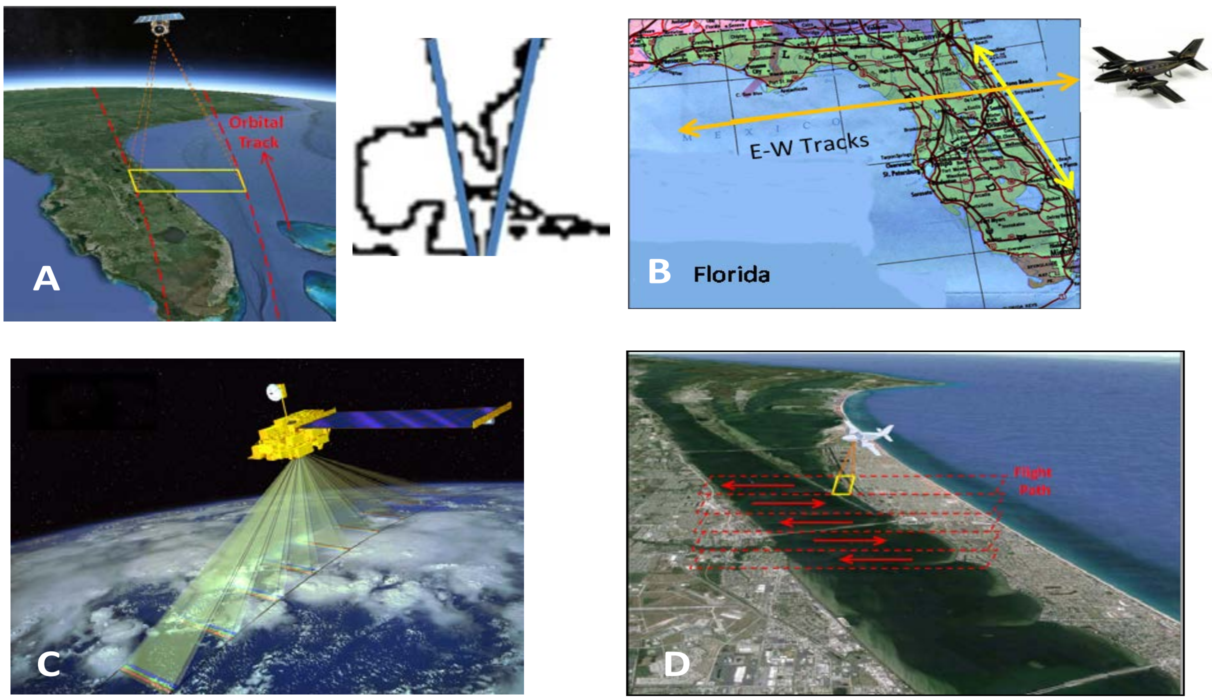

Figure 12. Schematic representation of sensor azimuthal directions for data collected in the E-W directions and N-S directions for operational hyperspectral multiangle sensing (A,B,D) airborne platforms described above. Satellite multi-angle systems (C) such as MISR and airMISR [1,2] (from: http://www-misr.jpl.nasa.gov/ (c). Airborne and vessel platform hyperspectral, multispectral digital sensors, high definition video cameras and photogrammetric camera based sensor data is available at www.bostater.info and in references [8,9,11,12,16] for coastal land and littoral waters along Florida.

Large field of view sensors as well as airborne and vessel tracks of multi-angle hyperspectral reflectance signatures are useful to helping to help assess land and water environmental management problems and issues. High spectral and spatial resolution sensing systems are also useful for monitoring and surveillance applications of land and water features, such as species discrimination, bottom top identification, vegetative stress or vegetation dysfunction assessments [13] and water bottom features (sand, vegetation, coral, muds). In order to help provide information for environmental quality or environmental security issues, it is safe to say that there will never be one set of multi-angle sensing azimuth and zenith angles for all applications. Thus scientific background studies are typically needed to characterize the multi-angle BRF characteristics.

3. SUMMARY AND CONCLUSIONS

The purpose of this paper has been to report on the development and acquisition of hyperspectral multi-angle imagery collected from different sensing platforms, including (a) rotation stage goniometers, (b) and a ground based linear goniometer. An image analysis approach for multi-angle hyperspectral pushbroom imagery is presented using the different systems, using the same compact HS imager [11,12] that can also be used in airborne operational environmental monitoring and surveillance. The approach outlined above makes use of calculating signature based anisotropic hyperspectral signatures and applying the inverse of this factor to a non-nadir HS image. The same technique can be applied for images collected as a function of sensor zenith angle or sensor azimuth angles. The generalized approach requires image to image registration of any 2 multi-angle reference HS pushbroom images. Example imagery of coastal vegetation species in Florida *Citrus meyeri and aurantifolia* using ground sample pixel sizes of a few mm is shown. The high spatial and spectral resolution hyperspectral imagery shown in this paper are examples of how ground based HS multi-angle imagery can be acquired as well as airborne or future satellite multi-angle imagery for characterization of the water surface, subsurface features and vegetative dysfunction assessments in coastal ecosystems.

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5. REFERENCES

[1] Diner, D., et al, "The Airborne Multi-angle Imaging SpectroRadiometer (AirMISR): Instrument Description and First Results", IEEE Transactions Geoscience Remote Sensing, IEEE Vol. 36, No. 4, pp. 1339-1349 (1998)

[2] Lyapustin, A., et al., "Local analysis of MISR surface BRF and albedo over GSFC and AERONET sites", IEEE Transactions Geoscience Remote Sensing, IEEE Vol. 44, No. 7, pp. 1707-1718 (2006)

[3 Harwin, S., Lucieer, A., "Assessing the Accuracy of Georeferenced Point Clouds Produced via Multi-View Stereopsis from Unmanned Aerial Vehicle (UAV) Imagery", Remote Sensing, Vol. 4, pp. 1573-1599 (2012)

[4] Diner, D., et al., "New Directions in Earth Observing: Scientific Applications of Multiangle Remote Sensing", Bulletin of the American Meteorological Society, Vol. 80, No. 11, pp. 2209-2228 (1999)

[5] Liang, S., Strahler, A., "Retrieval of Surface BRDF from Multiangle Remotely Sensed Data", Remote Sensing of Environment, Vol. 50, pp. 18-30 9 (1994)

[6] Slater, P., *Remote Sensing: Optics and Optical Systems*, Addison-Wesley Pub. Co., pp. 575 (1980)

[7] Martonchik, J., "Retrieval of surface directional reflectance properties using ground level multiangle measurements", Remote Sensing of Environment, Vol. 50, pp. 303-316 (1994)

[8] Bostater, C., Coppin, G., Levaux, F., Jones, J., Frystacky, H., "Mobile Platform Pushbroom Motion Control. Image Corrections and Spectral Band Selection: Examples of Hyperspectral Imagery Using Low Flying Aircraft and Small Vessels in Coastal Littoral Areas", In: Proceedings Robots for Risky Interventions and Environmental Surveillance-Maintenance (RISE-2011), International Advanced Robotic Program (IARP), 19 pp. (2003)

[9] Bostater, C., Coppin, G., Levaux, F., "Hyperspectral Remote Sensing – Using Low Flying Aircraft and Small Vessels in Coastal Littoral Areas", In: Remote Sensing- Advanced Techniques and Platforms, Boris Escalante-Ramerez (Ed.), InTech Publishers, ISBN: 978-953-51-0652-4, pp. 269-288 (2012)

[10] Jensen, J., Schill, S., "Bidirectional Reflectance Distribution Function (BRDF) Characteristics of Smooth Cordgrass (Spartina alterniflora) Obtained Using a Sandmeier Field Goniometer", Geocarto International, Vol. 15, No. 2, pp. 23-30 (2000)

[11] Bostater, C., Jones, J., Frystacky, H., Kovacs, M, "Integration, Testing, and Calibration of Imaging Systems for Land and Water Remote Sensing", SPIE Vol. 7825, pp. 199-215 (2010)

[12] Bostater, C., Jones, J., Frystacky, H., Kovacs, M, Jozsa, O., "Image Analysis for Water Surface and Subsurface Feature Detection in Shallow Waters", SPIE Vol. 7825, pp. 199-215 (2010)

[13] Bostater, C., "Imaging Derivative Spectroscopy for Vegetation Dysfunction Assessments", SPIE Vol. 3499, pp. 277-285 (1998)

[14] Dyer, S., *Wiley Survey of Instrumentation and Measurement*, john Wiley, pp. 1112, (2001)

[15] Sandmeier, S., Itten, K., “A Field Goniometer System (FIGOS) for Acquisition of Hyperspectral BRDF Data”, IEEE Transactions on Geoscience and Remote Sensing, Vol. 37, No. 2, pp. 978-986 (1999)

[16] Bostater, C., Frystacky, H., Levaux, F., “Enhanced Data Fusion Protocol for Surface and Subsurface Imaging of Released Oil in Littoral Zones”, In: Proceedings International Offshore and Polar Engineers (ISOPE), ISBN 978-1-880653-94–4, pp. 808-814 (2012)