The HICO Program – Hyperspectral Imaging of the Coastal Ocean from the International Space Station


Abstract - The HICO (Hyperspectral Imager for the Coastal Ocean) program is a collaboration between the Naval Research Laboratory (NRL), the University of Hawai‘i at Manoa, Utah State University, and NovaSol Inc., to image the coastal ocean and reef systems from the International Space Station. The first phase of the program will install the NRL Portable Hyperspectral Imager for Low Light Spectroscopy (PHILLS) in the Station Window Observational Research Facility (WORF), which has a nadir-facing optical window. The PHILLS will image in 10 nm bands over the wavelength range 400 to 1000 nm, and is designed to provide a signal-to-noise greater than 200 to 1 when viewing the relatively dark coastal ocean, coral, or on-shore vegetation. These images and ground truth will be used to develop and verify algorithms for water optical properties, chlorophyll, CDOM, bathymetry, bottom type, coral reef status, and to classify on-shore vegetation. The second phase of the program will install the University of Hawai‘i MAHI short wave infrared hyperspectral imager in the WORF. This paper introduces the HICO program, and discusses the PHILLS and its implementation for HICO.

I. INTRODUCTION TO THE HICO PROGRAM

The nadir-facing optical quality window in the Destiny module of the International Space Station (ISS) [1], shown from inside the Station in Figure 1, offers the opportunity to image the Earth from space from a shirtsleeve environment. The Window Observational Research Facility (WORF), which is yet to be launched, will provide payloads using the window with power, thermal management, and command and data links. The HICO (Hyperspectral Imager for the Coastal Ocean) [2] program is a collaboration between the Naval Research Laboratory (NRL), the University of Hawai‘i at Manoa, Utah State University, and NovaSol, Inc., to use the ISS window facility to image the coastal ocean and reefs on a global scale. The HICO program has been briefed to the DoD Space Experiments Review Board, and it is anticipated that the Space Test Program (STP) will integrate the payload with the Space Shuttle and ISS. HICO will image selected coastal and reef areas with sufficient frequency to capture seasonal variations, and will use the data to characterize and develop models for the coastal ocean, and characterize and monitor the health of reef environments.

The pressurized and temperature-controlled environment in the ISS, the ability to launch to the Station in a padded locker in the Space Shuttle with relatively low launch vibration, and the availability of Station crew for system setup, maintenance, and troubleshooting allow HICO to make use of hyperspectral imagers developed for airborne imaging. This avoids the substantial cost and development time of imagers designed for autonomous operation in a space environment. The ISS WORF power, thermal management, and command and data systems further simplify the system requirements compared to a dedicated space instrument. This opportunity will allow HICO to begin the substantial task of developing methods, algorithms, and data systems for space-based hyperspectral imaging of the coastal and ocean environments.

HICO will collect data from the ISS using two hyperspectral imagers, which will be operated sequentially for approximately one year each. The first on board will be the NRL Portable Hyperspectral Imager for Low Light Spectroscopy (PHILLS) [3], which images in the Visible and Near Infrared (VNIR) wavelengths from 400 to 1000 nm. The PHILLS is shown in Figure 2. The second imager will be the...
MAHI, which is being developed by the University of Hawai‘i and NovaSol, Inc. MAHI will image in the Short Wave InfraRed (SWIR) from 1000 to 2500 nm. Figure 3 shows the NovaSol Diamond-One, from which MAHI is being derived. The planned Ground Sample Distance (GSD) for PHILLS is 25 m, and for MAHI is 40 m. During operation, each imager will be mounted on a motorized gimbal system to be developed and fabricated by Utah State University. The gimbal system will provide ground motion compensation to reduce the apparent speed of the ground past the line of sight, and will also provide cross-track pointing to improve scene access. Following the completion of the HICO program, the gimbal system will be delivered to the Space Test Program, which intends to make it available for subsequent WORF payloads. The discussion below describes in more detail the NRL hyperspectral imager and its implementation for HICO.

II. THE PHILLS IMAGING SYSTEM

The NRL PHILLS is a pushbroom-scanning hyperspectral imager designed to produce high signal-to-noise images of the relatively low albedo coastal ocean and on-shore vegetation. The PHILLS imager, shown in Figure 2, is built using Commercial Off The Shelf (COTS) components wherever possible to minimize cost and development time. Light enters PHILLS through the foreoptic lens, which images the scene at the location of the spectrometer slit. The slit is the system field stop, and it allows only light originating from a line in the scene, parallel to the slit, to enter the spectrometer. Spectral dispersion in the direction perpendicular to the slit is produced by a HyperSpec™ VS-15 spectrometer, shown in cross section in Figure 4. This spectrometer was developed in collaboration between NRL and American Holographic, Inc., and an improved version is now available from Headwall Photonics. The spectrometer is an all-reflective Offner design incorporating a convex reflective grating corrected for astigmatism, and is further optimized by selecting the grating holographic construction points and mirror tilts to balance third- and fifth-order astigmatism. This spectrometer has inherently low smile (the change in dispersion with field position) and keystone distortion (the change in magnification with spectral position), both modeled to be less than 0.1%.

The spectrally dispersed image falls on a thinned, backside illuminated 1024 x 1024 silicon CCD in a camera from PixelVision, Inc. The wavelength range from 400 to 1000 nm is dispersed over approximately 500 pixels, yielding spectral resolution as fine as 1.2 nm. The focal plane assembly incorporates a custom zero order beam dump and an order-sorting filter. The backside illumination provides high quantum efficiency in the blue wavelengths, and the camera electronics provide 14-bit digitization and approximately 30 electrons read noise. These performance characteristics, along with ground motion compensation to increase the frame time, yield the high signal to noise ratio required to retrieve quality
data products from the low albedo coastal ocean scenes. The PHILLS foreoptic used for data collection from an aircraft is a COTS C-mount video lens from Schneider Inc., which is corrected over the wavelength range 400 to 1000 nm. The much higher altitude of the ISS and the 25 m GSD will require a longer focal length lens. A suitable lens designed to operate over the full PHILLS wavelength range is not commercially available, and therefore the PHILLS foreoptic for HICO will be custom designed and fabricated.

III. PHILLS IMPLEMENTATION ON THE INTERNATIONAL SPACE STATION

The PHILLS pushbroom mode of imaging is compatible with use on the ISS, where the forward motion of the aircraft environment for which the PHILLS was designed is replaced by the orbital motion of the Station. The PHILLS HICO data will be collected and stored in 10 nm spectral bins over the wavelength range 400 to 1000 nm, with 200 to 1 or greater signal-to-noise for coastal ocean scenes over the range of wavelengths that penetrate the water. Instrument modeling shows that a ground motion compensation factor of approximately ten will be required to achieve the planned signal-to-noise ratio, and orbit simulations have shown that cross track pointing of up to 30 degrees off nadir is required to achieve an acceptable scene revisit time of approximately ten days for any location accessible from the ISS orbit. The transmission of the Station optical-quality window varies over a range of tens of percent as a function of wavelength and angle of incidence [4], and this will have to be taken into account in the data processing.

The PHILLS HICO flight system will consist of: the PHILLS imager described above; a two axis gimbaled mount providing ground motion compensation and cross-track pointing; a Windows-based computer that controls the imaging process including receiving imaging scripts generated on the ground, receiving time and attitude data from the Station, receiving health and status data from the sensor system, controlling the imager, controlling the gimbal pointing and motion, operating a mechanical shutter to collect dark background frames, and processing and storing the data; and a power supply for the PHILLS, gimbal system, and computer. The computer will also implement the NRL Optical Real time Adaptive Spectral Identification System (ORASIS) algorithm [5], to provide approximately 10 to 1 compression of the hyperspectral data with negligible loss of fidelity. There is provision for some image and status data to be sent to the ground via Station telemetry for system checkout, system monitoring, and scenes requiring low data latency. However, current plans call for the bulk of the image, pointing, and ancillary data to be stored on ruggedized media and transported to the ground for analysis.

The Naval Research Laboratory will use the HICO data to investigate the use of existing and new algorithms to produce products of Naval utility using spaceborne hyperspectral imagery. The University of Hawai‘i will analyze the data to characterize and monitor the health of reef environments, and develop other data products of interest to the University’s research program. At NRL, emphasis will be placed on atmospheric correction, water optical properties, bottom type and reflectance, bathymetry, and the classification of near-shore vegetation and terrain. NRL will also use the variety of viewing geometries provided by the Station orbit to investigate the sensitivity of the product algorithms to the observing geometry, Sun angle, aerosol type, and the optical depth of the atmosphere.

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REFERENCES